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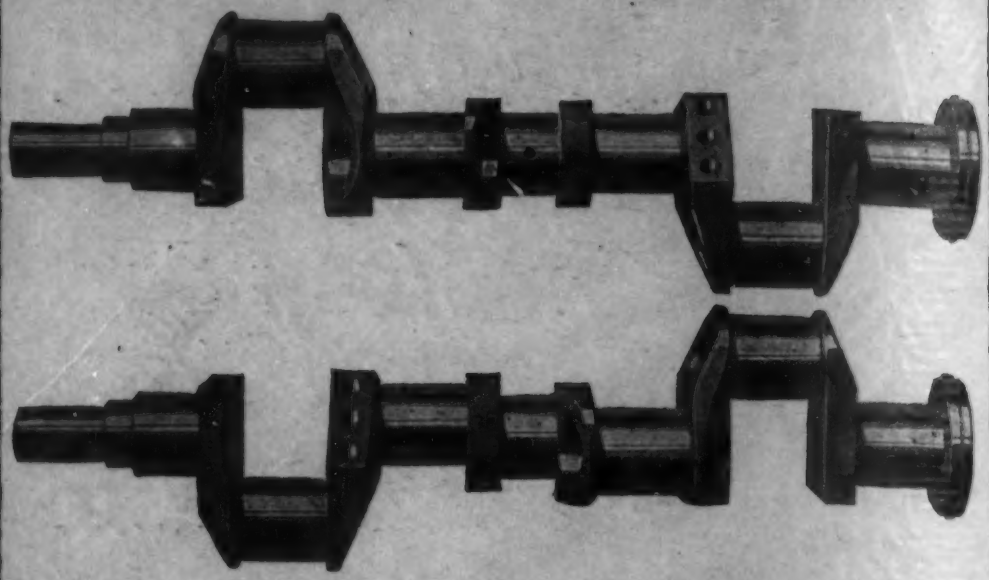

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TRANSACTIONS
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VOL. XVI SEPTEMBER, 1929 NO. 3

ON THE EQUILIBRIUM DIAGRAM OF THE IRON-MOLYBDENUM SYSTEM

By Takeshi Takei and Takejiro Murakami

Abstract

The equilibrium diagram of the iron-molybdenum system has been studied by microscopic investigation, the electric resistance method and by dilatometric and the magnetic analyses. In this system, two intermetallic phases (ϵ) and (η) exist, consisting of the compound Fe_3Mo_2 and FeMo respectively. These phases are formed by peritectic reactions melt $+ \eta \rightleftarrows \epsilon$, and melt $+ \delta' \rightleftarrows \eta$. The former forms a eutectic with alpha iron, dissolving molybdenum at 2625 degrees Fahr. (1440 degrees Cent.) in the range of composition of about 38 to 50 per cent of molybdenum; the latter decomposes to the epsilon phase and molybdenum dissolving iron at about 2155 degrees Fahr. (1180 degrees Cent.). The solubility of molybdenum in alpha iron is about 38 per cent at 2625 degrees Fahr. (1440 degrees Cent.), and it decreases to 6 per cent at room temperature. The A_2 point of the alpha solid solution is slightly lowered as the molybdenum content increases, while the A_3 point rapidly rises to 3 per cent of molybdenum. In alloys containing more than 63 per cent of molybdenum, a eutectoid is found, consisting of the eta-phase and molybdenum dissolving iron.

THE alloys of the iron-molybdenum system have been studied by Guillet, Vigouroux, Lautsch and Tammann and others. After considering the results of these investigators, Guertler con-

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structed the probable diagram, in which the formula of the intermetallic compound Fe_3Mo_2 or FeMo was not settled.

Recently, W. P. Sykes[1] proposed the equilibrium diagram shown in Fig. 1. According to his view, there exist, in this system, an intermetallic compound, Fe_3Mo_2, which is formed by a peritectic reaction at 2805 degrees Fahr. (1540 degrees Cent.), and this compound and the alpha phase form a eutectic at 2625 degrees

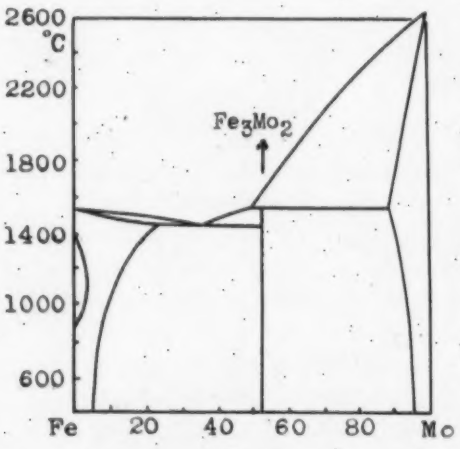

Fig. 1

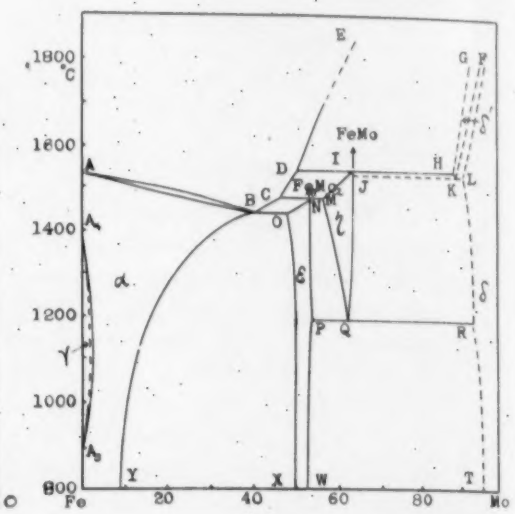

Fig. 2

Fig. 1—Equilibrium Diagram for the Iron-molybdenum System as Proposed by Sykes. Fig. 2—Equilibrium Diagram for the Iron-molybdenum System as Determined by the Present Experiment.

Fahr. (1440 degrees Cent.). On examining the photomicrographs in his paper, however, some doubt arose regarding the eutectic and other structures, and hence the present writers have undertaken to study this system further.

In the present work, alloys containing less than 50 per cent of molybdenum were prepared from electrolytic iron and a molybdenum powder containing about 0.1 per cent of carbon, while those with a high molybdenum content were prepared from reduced iron and molybdenum powder. As the molybdenum content exceeds 90 per cent, the specimens could not be melted completely, but they were well alloyed for microscopic examination. The investigation was carried out mainly by microscopic examination, while the magnetic analysis, the electric resistance and the dilatometric methods were applied in the case of some of the specimens.

[1]W. P. Sykes, "The Iron-Molybdenum System," TRANSACTIONS, American Society for Steel Treating, Vol. 10. 1926, p. 839.

Further an intermetallic compound was separated from one of the specimens by electrolysis, and its composition was determined by chemical analysis.

Equilibrium Diagram

Fig. 2 shows the equilibrium diagram for this system determined by the present experiment. In this system, there exist six solid phases α, γ, ϵ, η, δ and δ'. For iron-rich alloys its agreement with that given in Fig. 1 is almost complete, although the solubility at a high temperature of the ϵ-phase in the α-solid solution is markedly greater and the range of eutectic is very small; that is, the solubility at the eutectic temperature is 38 per cent of molybdenum, and the eutectic change takes place in the range from 38 to 50 per cent of molybdenum. Curve BY shows the change of solubility, and the horizontal line BO the eutectic temperature.

A solid solution, the ϵ-phase consisting of a compound Fe_3Mo_2, is formed by a peritectic reaction at a temperature between 2730 and 2640 degrees Fahr. (1500 and 1450 degrees Cent.), which is shown in a horizontal line CNM in Fig 2. Another solid solution, the η-phase, found in the present investigation, consists of a compound FeMo and is formed peritectically at 2805 degrees Fahr. (1540 degrees Cent.). The latter phase exists in the range from 56 to 63 per cent of molybdenum, and decomposes to the ϵ- and δ-phases at about 2155 degrees Fahr. (1180 degrees Cent.) by a eutectoid reaction. The horizontal line DIH shows the peritectic temperature and PQR the eutectoid change.

Molybdenum forms the δ solid solution dissolving about 5 per cent of iron at room temperature; the solubility gradually increases with the rise of temperature, as shown in curve TRL. Moreover, it is considered that in the alloys containing from 63 to 93 per cent of molybdenum, a eutectoid reaction takes place, and hence another solid solution δ' probably exists at a high temperature. The dotted line JKL shows the eutectoid temperature.

The A_2 point of α iron is slightly lowered by the addition of molybdenum, as shown in curve ab in Fig. 3; the compounds, Fe_3Mo_2 and FeMo are both nonmagnetic.

Microscopic Examination

All specimens prepared in the present work were subjected to

several heat treatments and the microstructure examined. The heating at high temperatures—above 2190 degrees Fahr. (1200 degrees Cent.) for annealing or quenching—was carried out in a Tammann furnace, in which the Tammann tube containing the specimen was placed, the temperature being measured with a Cambridge optical pyrometer. In order to protect it from oxidation and carburization hydrogen gas was passed over the specimen.

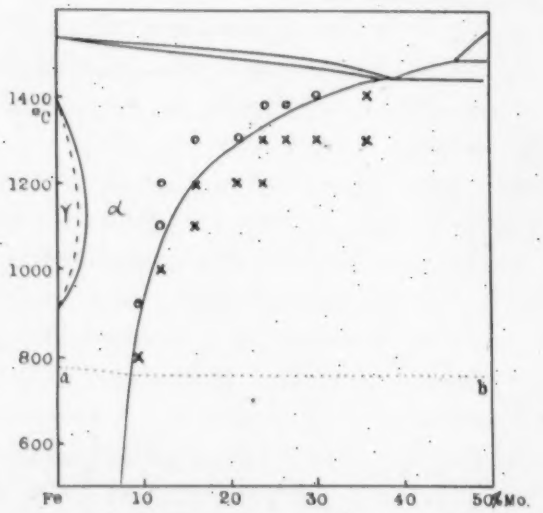

Fig. 3—Curves Showing Results of Experiments Made to Determine the Solubility Curve B Y of Fig. 2.

As the etching reagent, 30 per cent H_2SO_4 plus 5 per cent HNO_3 and 10 per cent KOH plus 10 per cent $K_3Fe(CN)_6$ solutions were used. 1 per cent H_2O_2 solution was also used for molybdenum-rich alloys.

Fig. 12 shows the structure of a specimen consisting of the α-phase. The γ-phase is always found in alloys containing less than 3 per cent of molybdenum when quenched at a high temperature—above 1650 degrees Fahr. (900 degrees Cent.)—as shown in Fig. 13, whereas those with a higher molybdenum content whether quenched or annealed consist of a single phase in agreement with the Sykes' result. When an alloy containing more than 6 per cent of molybdenum is slowly cooled, the ϵ-phase makes its appearance. As this phase is not attacked by the above acid solution, the differentiation of it from the α-phase is a very easy matter as is evidenced by Figs. 14 to 18. The alkaline ferricyanide solution causes no reaction with it. The fact that the solubility of the ϵ-phase in

the α-phase markedly increases as the temperature rises, and, consequently, that the eutectic reaction is limited to a narrow range—in disagreement with Sykes' result—is confirmed by the following fact. When alloys containing from 7 to 40 per cent of molybdenum are rapidly cooled from the melt, the ϵ-phase separates out regularly at the grain boundary and also at the cleavage of the α-phase, neither primary crystal nor eutectic structure being found, as is shown in Figs. 14 to 16. By long annealing at a high temperature, the separated ϵ-phase globulizes gradually, as shown in Fig. 17, owing to the surface tension of the ϵ-phase, though if these specimens are cooled slowly from the melt, elongated crystals of the ϵ-phase separated from the α-phase are obtained, as shown in Fig. 16. As the molybdenum content exceeds 40 per cent, the primary crystals of the ϵ-phase begin to appear (Fig. 18). In order to determine the solubility curve BY in Fig. 2, the following experiment was made. A series of alloys containing from 9.5 to 38.4 per cent of molybdenum were quenched from several temperatures between 1290 and 2550 degrees Fahr. (700 and 1400 degrees Cent.) and after heating them for 30 minutes at the required temperature they were examined microscopically. The result is shown in Fig. 3, in which the marks "o" show that the specimen consists of a single phase, and the marks "x" that it consists of two phases.

When an alloy with a molybdenum content ranging from 50 to 53 per cent is cooled slowly from the melt, the polygonal structure of the ϵ-phase occupies the whole area (Fig. 19), whereas when it is cooled rapidly, the α- and the η-phases appear with the ϵ-phase (Fig. 20), owing to the incompleteness of the peritectic reaction, melt $+ \eta \rightleftarrows \epsilon$. Moreover the ϵ-phase itself appears to consist of two parts, probably owing to the difference in the concentration (Fig. 21). By sufficient annealing at a higher temperature it may be made quite homogeneous, showing that the ϵ-phase is a solid solution consisting of Fe_3Mo_2 (53.4 per cent molybdenum) dissolved in iron.

As the molybdenum content increases to more than 53 per cent, a fine eutectoid structure is observable in an annealed specimen, as shown in Fig. 22; when the specimen is quenched at above 2190 degrees Fahr. (1200 degrees Cent.), the eutectoid changes to the η-phase which is colored light brown with the alkaline ferri-

cyanide solution as shown in Fig. 24. Its quantity gradually increases with the molybdenum content until it occupies the whole area in the alloy containing molybdenum which ranges from 57 to 63 per cent. This shows that the η-phase is a solid solution mainly consisting of the compound FeMo (63.2 per cent molybdenum).

If these alloys are rapidly cooled from a high temperature, a complicated structure is observable, as shown in Fig. 28, in which the pearlite structure is a eutectoid decomposed from the δ'-phase primarily separated from the melt, the dark area is another eutectoid decomposed from the η-phase formed by the peritectic reaction at the temperature DHI, and the white area is the ϵ-phase in which the α-phase is deposited. For the determination of the peritectic temperature of the reaction, melt $+ \eta \rightleftarrows \epsilon$, an alloy containing 54.9 per cent of molybdenum was quenched at 2550, 2640 and 2730 degrees Fahr. (1400, 1450 and 1500 degrees Cent.), respectively, after being sufficiently annealed at the required temperature, and the resulting structures were examined. The specimen quenched at 2730 degrees Fahr. (1500 degrees Cent.) (Fig. 23) contained a partially melted part, whereas in the other two, such a part was not observable, as shown in Fig. 24. Hence, the line CM in Fig. 2 or the peritectic temperature should be a point between 2640 and 2730 degrees Fahr. (1450 and 1500 degrees Cent.). The η-phase appears in the alloys containing more than 46 per cent of molybdenum when cooled rapidly, and hence, the lower limit of the molybdenum content for the reaction—melt $+ \eta \rightleftarrows \epsilon$ (point C in Fig. 2)—will be about 46 per cent.

For the determination of the line DH in Fig. 2, two specimens containing, respectively, 85 and 86.9 per cent of molybdenum were treated in the same way as above, and it was ascertained that the line lies between 2730 and 2820 degrees Fahr. (1500 and 1550 degrees Cent.). Considering the result, the peritectic temperature for the reaction, melt $+ \delta' \rightleftarrows \eta$, seems to be the one given by Sykes as the peritectic temperature 2805 degrees Fahr. (1540 degrees Cent.) for the reaction, Mo + melt $\rightleftarrows$ Fe_3Mo_2.

The occurrence of a eutectoid reaction, $\eta \rightleftarrows \epsilon + \delta$, is clearly demonstrated by the microscopic examination. In alloys containing from 56 to 90 per cent of molybdenum, the eutectoid structure is distinctly seen under a high magnification, as shown in Fig. 31 after etching the specimen with acid. If the magnification is

not sufficiently high, the constituents cannot be discriminated, being etched dark, as shown in Figs. 28 and 30. On applying the alkaline ferricyanide solution, it is easily etched dark brown. The eutectoid structure is always observable around another eutectoid formed from the δ'-phase, and in alloys having no proeutectoid δ-crystal, the structure does not readily appear, probably owing to the fact that the δ-phase hardly separates. When an alloy consisting of the ϵ- and the η-phase, or the η-phase only, is cooled moderately only a part of the η-phase is decomposed, whereas in alloys containing the proeutectoid δ-phase, the decomposition is almost complete (Fig. 30). If, however, the former alloy is very slowly cooled or annealed for a long time at about 1830 to 2010 degrees Fahr. (1000 to 1100 degrees Cent.), the decomposition is completed, as shown in Figs. 22, 26 and 27.

The eutectoid temperature was estimated from the change in the microstructure of quenched specimens. When the alloys containing the eutectoid structure are quenched at 2280 degrees Fahr. (1250 degrees Cent.) or at a higher temperature, after being heated for about 30 minutes at that temperature, the η-phase is observable instead of the eutectoid structure (Fig. 29), whereas in the alloys quenched at 2100 degrees Fahr. (1150 degrees Cent.) or a lower temperature, the eutectoid structure is left unaltered. Hence the eutectoid temperature will be about 2190 degrees Fahr. (1200 degrees Cent.) : according to the result of the measurement of the electric resistance the temperature is 2155 degrees Fahr. (1180 degrees Cent.).

A pearlite-like structure observable in alloys containing more than 63 per cent of molybdenum (Figs. 28 and 30) disappears on quenching at 2820 degrees Fahr. (1550 degrees Cent.) or a higher temperature and the melted part is frequently observable around the δ'-phase (Fig. 32), whereas alloys containing 90 or more per cent of molybdenum (after the same treatment) consist of large well-defined polygonal grains (Fig. 33). These changes are well illustrated by the diagram in Fig. 2.

In alloys containing from 90 to 93 per cent of molybdenum cooled in a furnace, a well-developed eutectoid structure at the grain boundary of the δ-crystal is seen (Fig. 34). If, however, these specimens are slowly cooled, fine crystals of the ϵ-phase precipitate from the δ-phase owing to the decrease in solubility, as

shown in Fig. 35. By long annealing at a temperature below 2640 degrees Fahr. (1450 degrees Cent.) the precipitates are globulized.

The fine crystals of the ϵ-phase observable in an alloy containing about 94 per cent of molybdenum disappear on quenching from 1830 degrees Fahr. (1000 degrees Cent.) owing to the increase in the solubility with the rise of temperature, though the polygonal structure is ill-defined. But alloys containing more than 95 per cent of molybdenum consist of a single phase irrespective of the rate of cooling. The polygonal structure is clearly seen if the specimen is quenched from above 2910 degrees Fahr. (1600 degrees Cent.), while in the annealed specimen the grain boundary is hardly observable.

Sykes considers that this pearlite-like structure was formed by the Fe_3Mo_2 separated along the solubility curve: from the fact above described and from the characteristic structure, however, the writers believe in the existence of a eutectoid change, as shown in the diagram (Fig. 2). It is probable that on account of the decreasing solid solubility of the ϵ-phase in the δ- solid solution with falling temperatures, the ϵ-phase separates from the δ- solid solution during cooling, and disturbs the characteristic structure consisting of primary crystals and eutectoid. Such a structure will, however, not be formed without any eutectoid change.

If the eutectoid change takes place, the existence of a polymorphic transformation in molybdenum is inferred. E. C. Brom[2] measured the electric resistance of the molybdenum filament up to 3632 degrees Fahr. (2000 degrees Cent.), and no discontinuity was observable over this range of temperature. We have also made some experiments dealing with this point but with no success, and hence, the possible change in the range on the molybdenum side is indicated by a dotted line in Fig. 2.

Magnetic Analysis

For the magnetic analysis, alloys containing less than 7.9 per cent of molybdenum were forged in the form of rods 7 centimeters long and 5 millimeters thick, while those of a higher molybdenum content were cast in the same form and used after anneal-

[2]Physical Review of the American Physical Society, Vol. 13, 1919, p. 308.

ing. The intensity of magnetization at different fields was measured at room temperature by a ballistic galvanometer. The results are shown in Fig 4. By the addition of molybdenum, the intensity of magnetization is gradually decreased; the amount of decrease is small in the range of alloys consisting of the α-phase alone, whereas in those consisting of the two phases, α and ε, the decrease is conspicuous.

The intensity of magnetization at high temperatures was measured by the magnetometric method, the magnetizing field

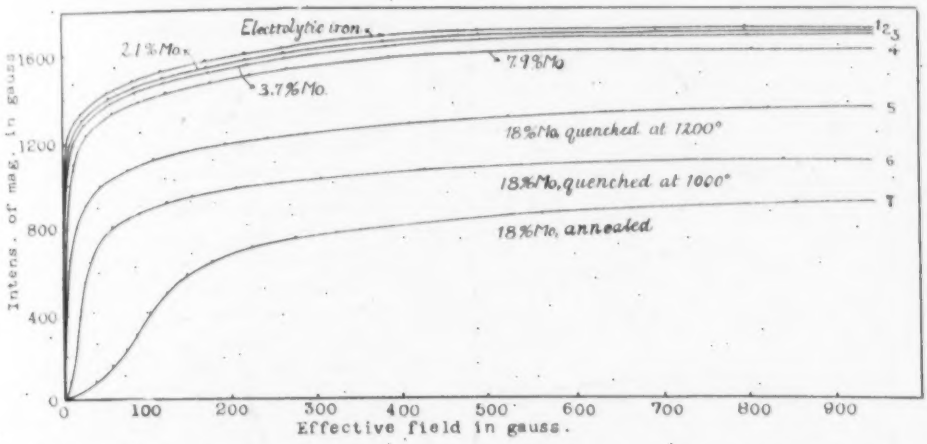

Fig. 4.—Curves Showing Results of Magnetic Analysis at Different Fields Measured at Room Temperature.

applied being about 200 gausses. The result for the annealed specimens is shown in Fig. 5, from which it is clearly seen that the intensity of magnetization decreases gradually with the rise of temperature and rapidly at the critical point, which is only slightly lowered by the addition of molybdenum. The change at the critical point decreases in amount as the molybdenum content increases, up to 50 per cent, owing to the fact that the magnetic α-phase in the specimen decreases and the nonmagnetic ε-phase increases.

The result for quenched specimens is shown in Figs. 6, 7 and 8. Specimens containing more than 6 per cent of molybdenum, i. e., consisting of the two phases, α and ε, at room temperature show a higher intensity of magnetization in the heating curve than in the cooling, as shown in Fig. 6. That is, the intensity of magnetization of the quenched specimen decreases on annealing, the amount of the decrease being much greater on increasing the

molybdenum content and raising the temperature of quenching. This fact may be explained as follows: As mentioned above, in an annealed state the intensity of magnetization of alloys gradually decreases in the case of those consisting of the α-phase alone as the molybdenum content increases, while in alloys consisting of the α- and ϵ-phases the decrease is conspicuous owing to the increase

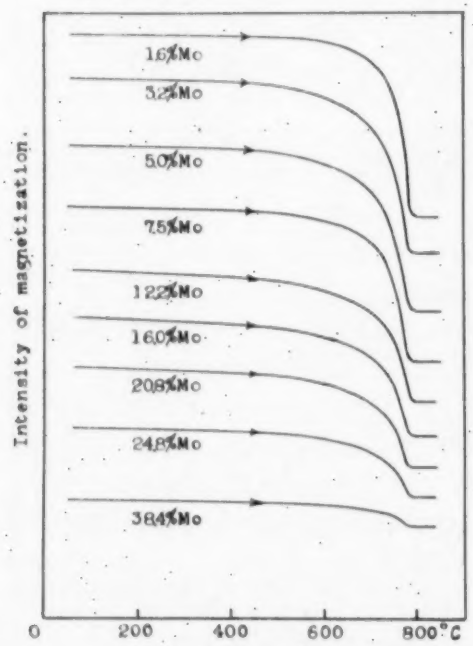

Fig. 5

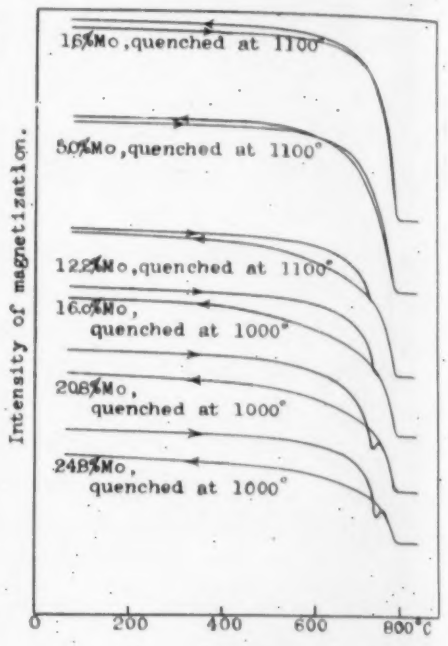

Fig. 6

Fig. 5—Curves Showing Results of Magnetic Tests on Annealed Specimens of Different Molybdenum Content. Fig. 6—Magnetization Curves Showing a Higher Intensity of Magnetization in the Heating Curves Than in the Cooling Curves.

of the nonmagnetic ϵ-phase. If the specimen is quenched from a high temperature, the α-phase increases in amount, dissolving the ϵ-phase in supersaturation, and hence, the intensity should be increased owing to the decrease of the nonmagnetic phase. If, however, the specimen is heated, the ϵ-phase is deposited from the supersaturated α-phase, and hence, the intensity should be decreased owing to the increase of the nonmagnetic phase. The amount of deposition is greater as the molybdenum content increases and the quenching temperature rises.

The intensity of magnetization of these quenched specimens gradually decreases at first with the rise of temperature, and an abnormal change, or an increase of the intensity, takes place at a temperature above 1290 degrees Fahr. (700 degrees Cent.). The

amount of the abnormal change increases as the molybdenum content increases, as shown in Fig. 6, and also with the rise of the quenching temperature, as shown in Figs. 7 and 8. From the change of microstructure of the quenched specimen on heating, it is definitely inferred that the abnormal change of magnetization is to be attributed to the deposition of the ϵ-phase. That is, if the

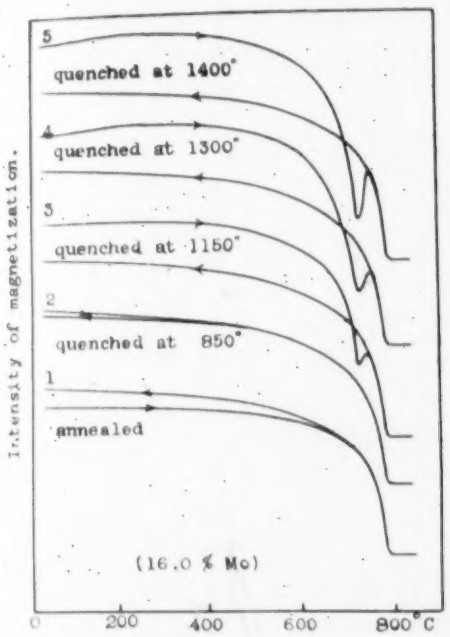

Fig. 7

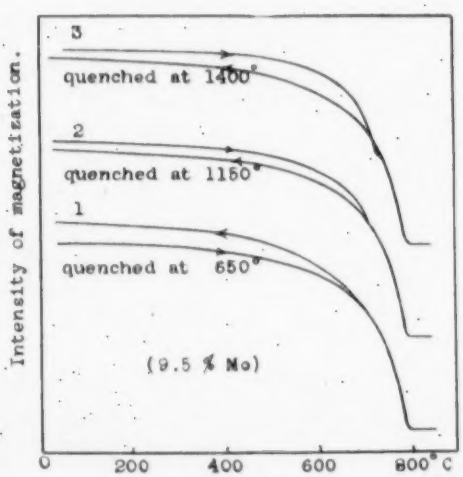

Fig. 8

Fig. 7—Curves Showing Intensity of Magnetization at Various Temperatures of Variously Treated Specimens Containing 16 Per Cent Molybdenum. Fig. 8—Curves Showing Intensity of Magnetization at Various Temperatures of Quenched Specimens Containing 9.5 Per Cent Molybdenum.

quenched specimen is heated to about 1470 degrees Fahr. (800 degrees Cent.), the ϵ-phase separates extensively, whereas no change is observable, if the heating temperature is less than 1200 degrees Fahr. (650 degrees Cent.). Since the magnetic critical point of the α-phase is gradually lowered with the increase of the molybdenum content, it is probable that the critical point of the supersaturated α-phase would be lower than that in the saturated state, and hence, the subsequent heating of the quenched specimen, or the deposition of the ϵ-phase, should result in the rise of the critical point. Hence, the abnormal change observable on the heating of the quenched specimen may be attributed to the superimposed effect of the following two factors. The decrease in the magnetization begins at the lower temperature in the quenched specimen

owing to the lowering of the critical point. If, however, the deposition of the ε-phase occurs, the critical point rises and the magnetization should be increased. When the deposition is completed, the change of the intensity is that of the saturated α-phase and it rapidly falls at the critical point.

Besides these changes, a small increase in the intensity of

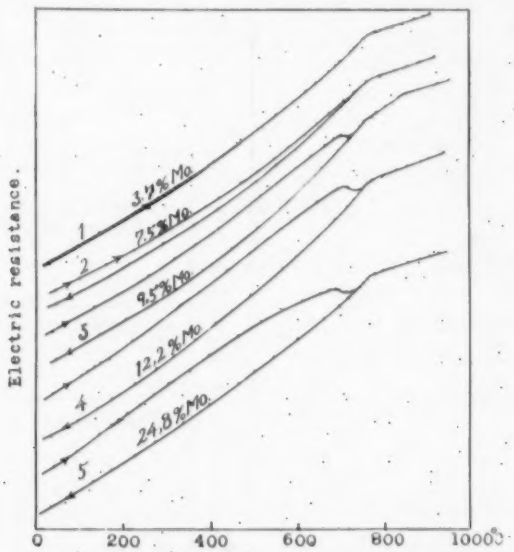

Fig. 9—Curves Showing the Electric Resistance of Samples Containing Varying Amounts of Molybdenum at Different Temperatures.

magnetization was observable at a temperature above 212 degrees Fahr. (100 degrees Cent.) (curves 4 and 5 in Fig. 7). This increase is probably due to the removal of the strain suffered during quenching.

Measurement of the Electric Resistance

The electric resistance of the iron-rich alloys was measured during heating and cooling, a specimen cast in the form of a rod being used. In annealed specimens no marked change was observable in the electric resistance-temperature curves except a slight bending and a break which is attributable to the change in solubility of the ε-phase. If, however, the specimens consisting of the α- and ε-phases, are quenched from a high temperature they show an abrupt change in electric resistance on heating them at about 1290 degrees Fahr. (700 degrees Cent.), and the greater the molyb-

denum content, the more conspicuous is the change, as shown in Fig. 9. This abnormal change corresponds to that observed in the magnetic analysis owing to the deposition of the ϵ-phase.

In order to ascertain the temperature for the eutectoid reaction $\eta \rightleftarrows \epsilon + \delta$, the electric resistance was measured during heating and cooling with an alloy containing about 60 per cent of molybdenum, two pairs of tungsten wires insulated from each other by quartz tubes being used as leads. A change is always observable at 2155 to 2175 degrees Fahr. (1180 to 1190 degrees Cent.), as is

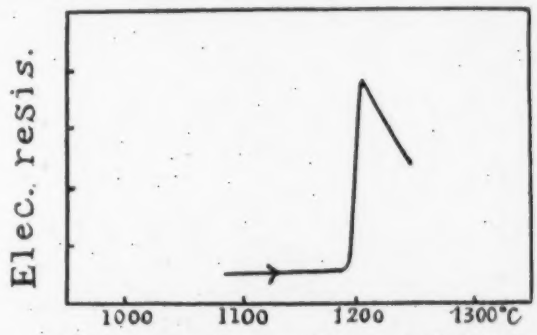

Fig. 10—Curves Showing Change of Electric Resistance Observable at 2155 to 2175 Degrees Fahr. (1180 to 1190 Degrees Cent.).

shown in Fig. 10, although the curves are not quite reversible in heating and cooling owing to the cracks caused by the volume change. Thus, the result of the measurement of the electric resistance confirms that of the microscopic examination.

Dilatometric Measurement

In the case of iron-rich alloys, the dilatometric change was measured during heating and cooling. The specimens used were cast in the form of rods, 5 millimeters thick and 8 centimeters long and annealed before measurement. The result is shown in Fig. 11. In the alloys containing less than 2 per cent of molybdenum, an abrupt change due to $\alpha \rightleftarrows \gamma$ is clearly seen (curves 1 and 2), while in those containing more than 4 per cent of molybdenum, the change is not observable, this fact being in agreement with the result of the microscopic examination.

In the alloys containing more than 7.5 per cent of molybdenum quenched at a high temperature, an abrupt change at about 1290 to 1330 degrees Fahr. (700 to 720 degrees Cent.) is observable

during heating, the amount of which increases with the molybdenum content, as is shown in curves 6 and 7. This change may also be attributed to the gradual deposition of the ε-phase from the supersaturated α- solid solution, as described in the case of the magnetic analysis and the electric resistance measurement.

Determination of the Composition of the Epsilon-Phase

The intermetallic compound existing in this system has already been studied by many investigators, namely Carnot and Goutal,[3]

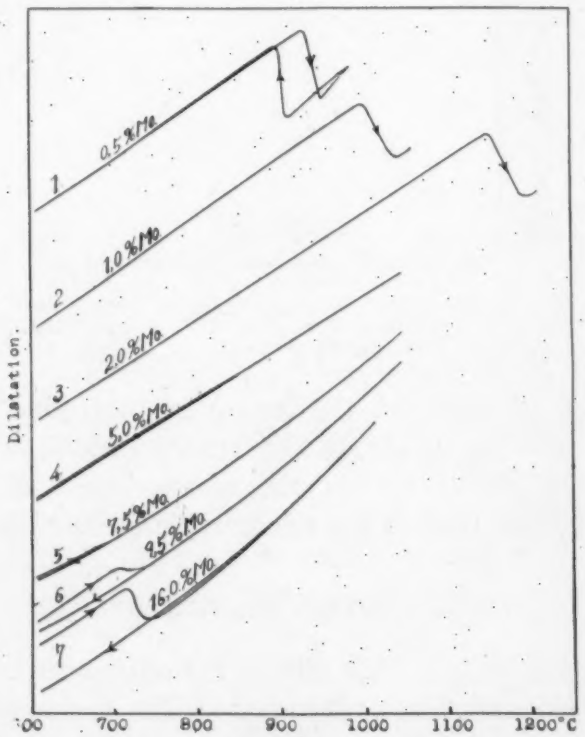

Fig. 11—Curves Showing Dilatometric Changes Occurring During Heating and Cooling in Specimens Containing Various Amounts of Molybdenum.

Vigouroux and others. Carnot and Goutal obtained a compound of the composition Fe_3Mo_2, while Vigouroux assumed the existence of the compounds Fe_2Mo, Fe_3Mo_2, FeMo and $FeMo_2$ by analysis of the insoluble matter obtained from alloys containing from 12 to 76 per cent of molybdenum by treating them with hydrochloric acid.

[3] *Comptes Rendus*, Vol. 75, 1897, p. 215.

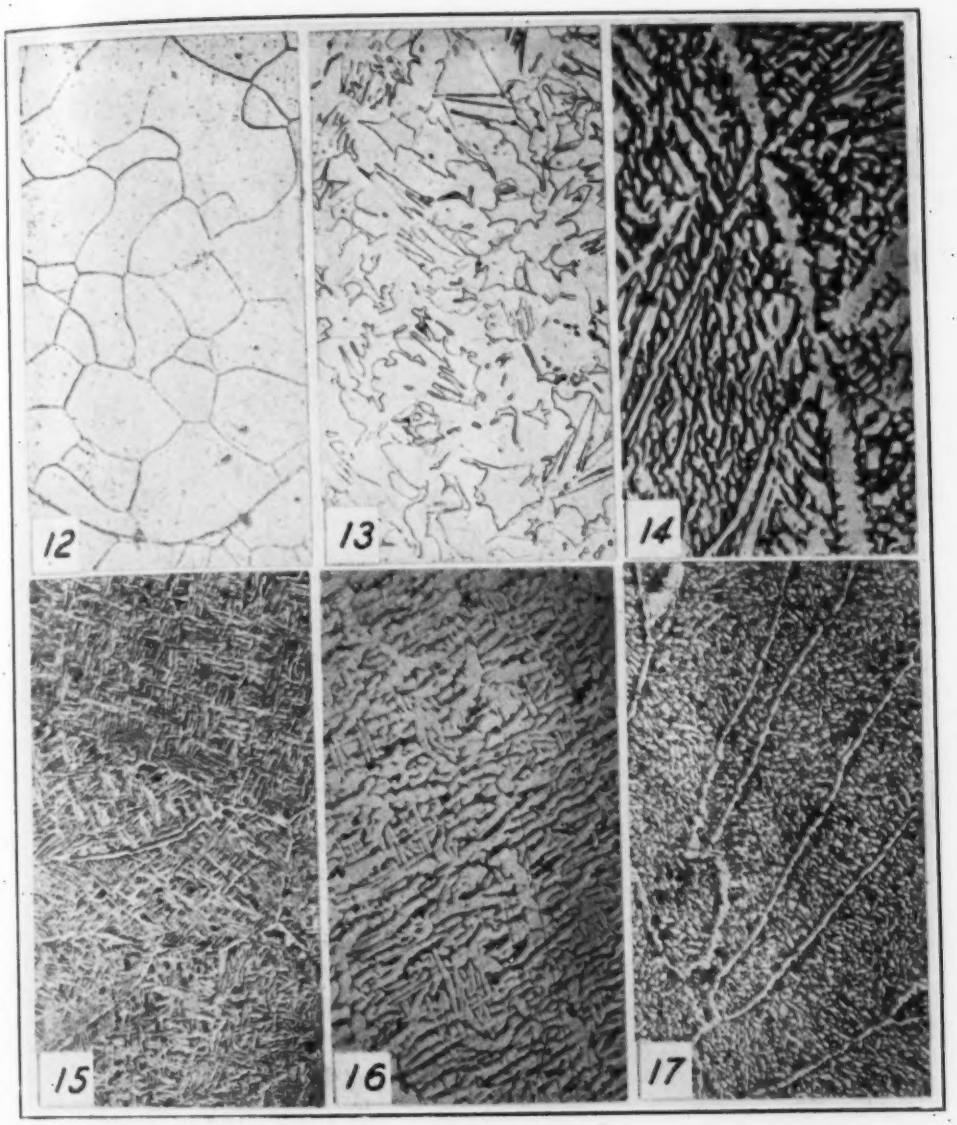

Fig. 12—Photomicrograph of Specimen Containing 1.6 Per Cent Molybdenum, Annealed. × 100. Fig. 13—Photomicrograph of Specimen Containing 1.6 Per Cent Molybdenum, Quenched at 2012 Degrees Fahr. (1100 Degrees Cent.). × 100. Fig. 14—Photomicrograph of Specimen Containing 30 Per Cent Molybdenum. Slowly Cooled from Melt and Annealed. × 400. Fig. 15—Photomicrograph of Specimen Containing 30.2 Per Cent Molybdenum. Chill Cast. × 400. Fig. 16—Photomicrograph of Specimen Containing 36.0 Per Cent Molybdenum. Slowly Cooled from Melt. × 100. Fig. 17—Photomicrograph of Specimen Containing 38.4 Per Cent Molybdenum. Chill Cast and Annealed. × 100. All Specimens Etched in Nitric and Sulphuric Acid.

The writers have undertaken to isolate the ϵ-phase by electrolysis and to determine its composition for the confirmation of the equilibrium diagram, Fig. 2. For this purpose, two alloys containing 20 and 30 per cent of molybdenum were selected as

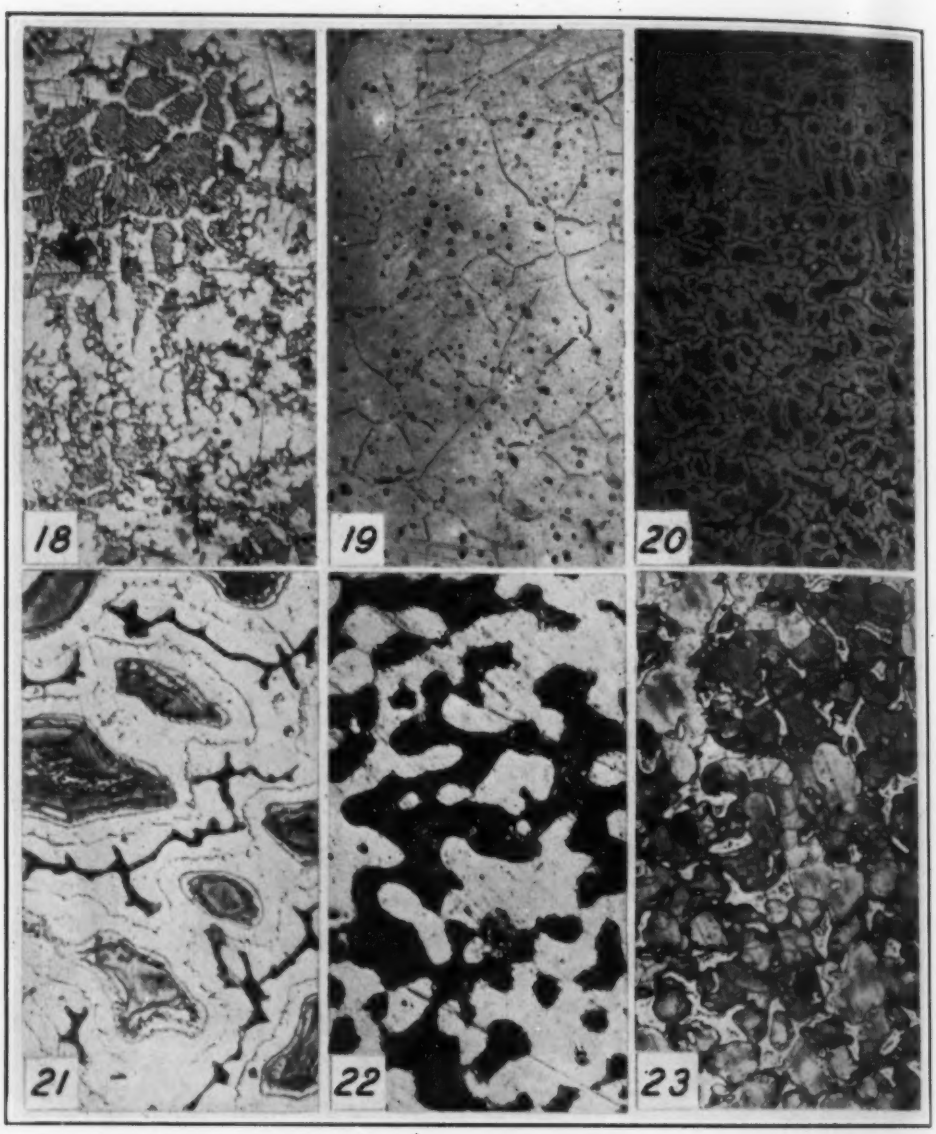

Fig. 18—Photomicrograph of Specimen Containing 42.7 Per Cent Molybdenum. Rapidly Cooled from Melt. Etched with Nitric and Sulphuric Acid. × 130. Fig. 19—Photomicrograph of Specimen Containing 49.9 Per Cent Molybdenum. Annealed. × 100. Fig. 20—Photomicrograph of Specimen Containing 52.2 Per Cent Molybdenum. Rapidly Cooled from Melt. × 100. Fig. 21—The Same Specimen as No. 20. × 400. Specimens Shown in Figs. 19, 20 and 21 Etched with Nitric Acid, Sulphuric Acid and Potassium Ferricyanide. Fig. 22—Photomicrograph of Specimen Containing 54.9 Per Cent Molybdenum. Annealed. × 100. Fig. 23—Photomicrograph of Specimen Containing 54.9 Per Cent Molybdenum. Quenched at 2732 Degrees Fahr. (1500 Degrees Cent.). × 100. Specimens Shown in Figs. 22 and 23 Etched in Potassium Ferricyanide.

these alloys consist of α- and ϵ-phases, as shown in Fig. 14, the former being soluble in acid and the latter insoluble. They were slowly cooled from the melt and were annealed at about 1560

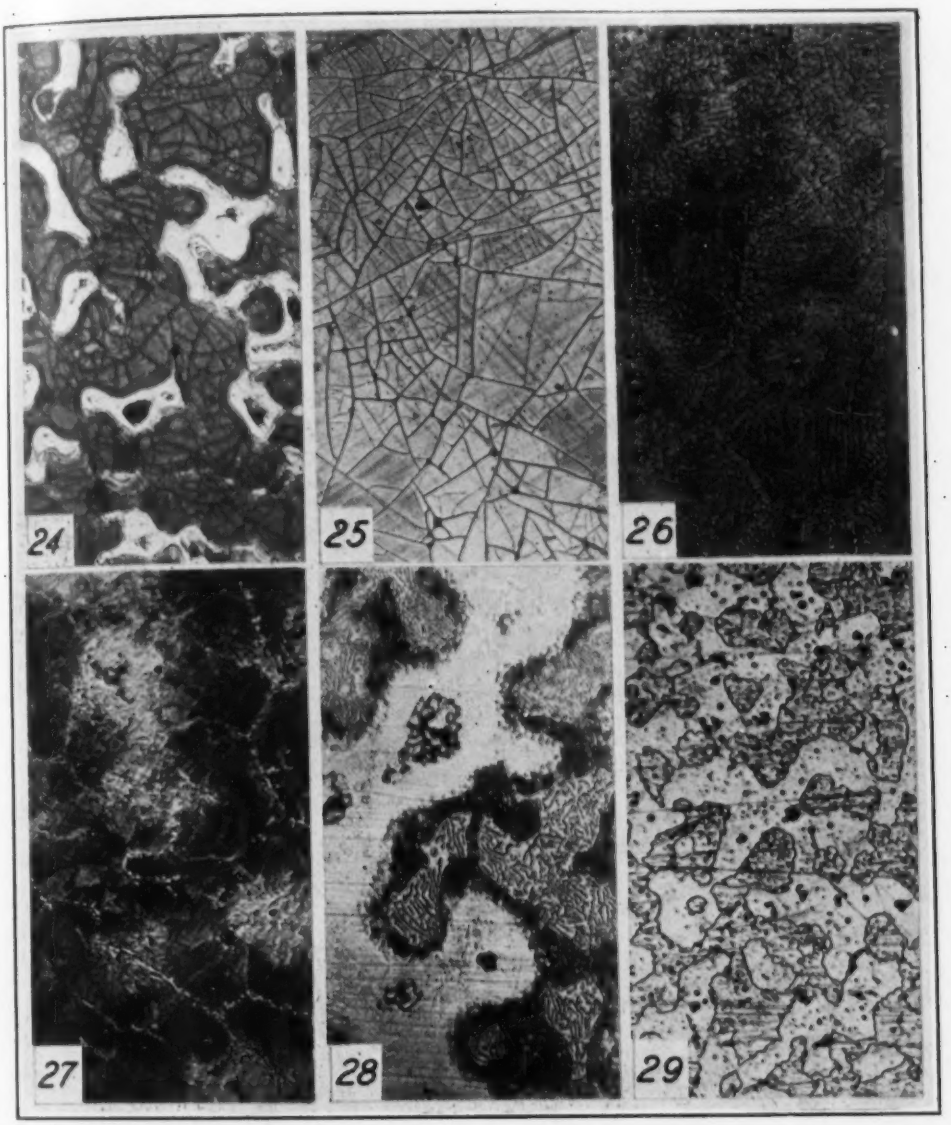

Fig. 24—Photomicrograph of Specimen Containing 54.9 Per Cent Molybdenum. Quenched at 2642 Degrees Fahr. (1450 Degrees Cent.). × 100. Fig. 25—Photomicrograph of Specimen Containing 60.5 Per Cent Molybdenum. Quenched at 2552 Degrees Fahr. (1400 Degrees Cent.). × 400. Specimens Shown in Figs. 24 and 25 Etched with Potassium Ferricyanide. Fig. 26—Photomicrograph of Specimen Containing 60.5 Per Cent Molybdenum. Slowly Cooled from 2552 Degrees Fahr. (1400 Degrees Cent.). × 400. Fig. 27—Photomicrograph of Specimen Containing 60.5 Per Cent Molybdenum. Rapidly Cooled from 2552 Degrees Fahr. (1400 Degrees Cent.) and Annealed at 2012 Degrees Fahr. (1100 Degrees Cent.). × 400. Specimens Shown in Figs. 26 and 27 Etched with Nitric Acid and Sulphuric Acid. Fig. 28—Photomicrograph of Specimen Containing 63.0 Per Cent Molybdenum. Rapidly Cooled from Melt and Annealed at 2012 Degrees Fahr. (1100 Degrees Cent.). × 400. Etched with Nitric Acid, Sulphuric Acid and Potassium Ferricyanide. Fig. 29—Photomicrograph of Specimen Containing 80.6 Per Cent Molybdenum. Quenched at 2642 Degrees Fahr. (1450 Degrees Cent.). × 400. Etched with Nitric Acid and Sulphuric Acid.

degrees Fahr. (850 degrees Cent.) in a current of hydrogen gas before being subjected to electrolysis. The electrolysis was carried out

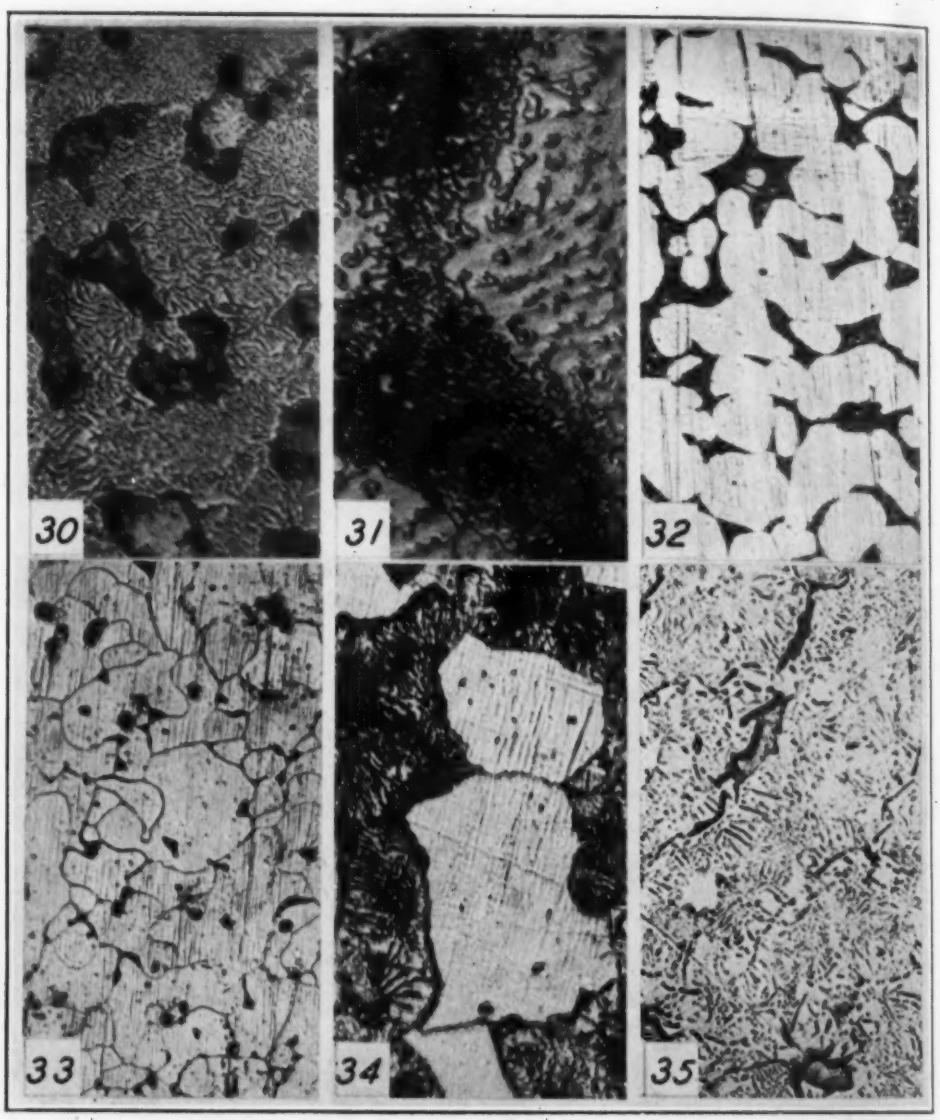

Fig. 30—Photomicrograph of Specimen Containing 80.6 Per Cent Molybdenum. Annealed. × 400. Fig. 31—Photomicrograph of Specimen Containing 80.6 Per Cent Molybdenum. Slowly Cooled from 2552 Degrees Fahr. (1400 Degrees Cent.) and Annealed at 2012 Degrees Fahr. (1100 Degrees Cent.). × 1000. Specimens in Figs. 30 and 31 Etched with Nitric Acid and Sulphuric Acid. Fig. 32—Photomicrograph of Specimen Containing 86.9 Per Cent Molybdenum. Quenched at 2858 Degrees Fahr. (1570 Degrees Cent.). Etched with Potassium Ferricyanide. × 100. Fig. 33—Photomicrograph of Specimen Containing 90.2 Per Cent Molybdenum. Quenched at 2822 Degrees Fahr. (1550 Degrees Cent.). Etched with Nitric Acid and Sulphuric Acid. × 100. Fig. 34—Photomicrograph of Specimen Containing 91.8 Per Cent Molybdenum. Cooled in a Furnace from 2912 Degrees Fahr. (1600 Degrees Cent.). × 400. Fig. 35—Photomicrograph of Specimen Containing 90.2 Per Cent Molybdenum. Annealed. × 400. Specimens Shown in Figs. 34 and 35 Etched with Potassium Ferricyanide.

at room temperature with a current density of 0.1 to 0.2 amperes per square centimeter in a diluted solution of hydrochloric acid

(sp. gr. 1.04). The residue was washed several times with distilled water by decantation after boiling it with the diluted hydrochloric acid, and filtered in a porcelain filter-crucible, being finally dried in a vacuum. The product is a grayish powder and is so stable that no trace of decomposition was observable during the above treatment.

Analyzing the powder, the following result was obtained:

Alloys No.	Iron Per Cent	Molybdenum Per Cent
1 (20 Per Cent Molybdenum)	52.0	48.4
2 (30 Per Cent Molybdenum)	49.1	50.5

In the case of specimen No. 1, the result was not satisfactory as the ϵ-phase in it was very fine, while in the case of specimen No. 2, the powdered ϵ-phase was rather coarse, and hence the result obtained from the latter seems to be more correct. At any rate, the molybdenum content obtained is higher than that corresponding to the compound Fe_2Mo (46.2 per cent molybdenum), but is lower than that corresponding to Fe_3Mo_2 (53.4 per cent molybdenum). As the original alloys consist of the α-phase of the composition indicated by the point Y in Fig. 3 and the ϵ-phase of the composition indicated by X, and the α-phase is completely dissolved into the solution, the composition of the residue should be that shown by the point X. Hence, it is probable that the ϵ-phase is a solid solution of Fe_3Mo_2 dissolving some iron.

Summary

The results of the experiments so far described may be summarized as follows:

1. The equilibrium diagram of the iron-molybdenum system has been obtained by microscopic examination, the electric resistance measurement and the dilatometric and magnetic analyses.

2. The A_4 point is lowered steadily, and the A_3 point rises rapidly until the α-iron and δ-iron areas unite at 3 per cent of molybdenum.

3. The solubility of the ϵ-phase in the α-phase is determined to be 6 per cent of molybdenum at room temperature and, as the temperature is raised, it increases up to about 38 per cent of molybdenum at the eutectic point viz. 2625 degrees Fahr. (1440 degrees Cent.).

4. The ϵ-phase consisting of the compound Fe_3Mo_2 is formed by the peritectic reaction, melt $+ \eta \rightleftarrows \epsilon$, at a temperature between 2640 and 2730 degrees Fahr. (1450 and 1500 degrees Cent.) on cooling, and forms a eutectic with the α-phase.

5. The η-phase, consisting of the compound FeMo, is formed by the peritectic reaction, melt $+ \delta' \rightleftarrows \eta$, at 2804 degrees Fahr. (1540 degrees Cent.), and decomposes by a eutectoid reaction into the ϵ- and δ-phases at about 2155 degrees Fahr. (1180 degrees Cent.).

6. In alloys containing more than 63 per cent of molybdenum, another eutectoid change, $\delta' \rightleftarrows \delta + \eta$, takes place at about 2730 degrees Fahr. (1500 degrees Cent.).

7. The A_2 point is slightly lowered with the increase of the molybdenum content.

8. The intensity of magnetization gradually decreases as the molybdenum content increases up to 50 per cent, the ϵ- and the η-phases being both nonmagnetic.

9. In the case of the alloys containing the α- and the ϵ-phases at room temperature the intensity of magnetization is increased by quenching at a high temperature and the magnetization returns to its normal state on heating the specimens up to 1290 degrees Fahr. (700 degrees Cent.).

DISCUSSION

Written Discussion: By W. P. Sykes, Cleveland Wire Division, General Electric Co., Cleveland.

There are several points of interest in this paper upon which the authors are to be commended. The magnetic analysis shows very nicely the effect of precipitation of the Fe_3Mo_2 from a supersaturated solid solution when the temperature is raised to about 1290 degrees Fahr. (700 degrees Cent.) It would be of interest to know the heating rate employed in these measurements, since the shape of the magnetization curve in heating quenched alloys in the range of 1110 to 1470 degrees Fahr. (600 to 800 degrees Cent.) will depend upon the rate of precipitation.

Note from these curves that the molybdenum is more effective in lowering the intensity of magnetization when present as the compound than when in solid solution in the iron.

The abrupt decrease in electrical resistance occurring at about 1290 degrees Fahr. (700 degrees Cent.) in the supersaturated iron-rich alloys is quite in accord with the generally observed phenomenon in other alloy systems in which the resistance decreases as precipitation progresses. The dilatation temperature curves in Fig. 2 confirm the volume decrease co-

incident with age hardening of the iron-rich alloys previously reported by the writer. Also the alpha to gamma change in the 2-per cent molybdenum alloy at about 2100 degrees Fahr. (1150 degrees Cent.) is clearly illustrated in this figure.

In the light of the equilibrium diagram presented in this paper, the writer has carefully examined the composition ranges in question. Freshly prepared alloys were used for this work and special precautions observed in the meltings and heat treatments to insure uniformity of composition and approach closely to conditions of true equilibrium. With one exception, no evidence is found to warrant any modification of the diagram as previously presented by the writer. This exception is the eta (η) phase of the authors existing in the range between 54 and 63 per cent of molybdenum and between the temperatures of 2155 and 2805 degrees Fahr. (1180 and 1540 degrees Cent.) This phase will be discussed later.

The eutectic unquestionably exists between 23 and 53 per cent molybdenum. It is impossible to heat an alloy in this range of composition without the formation of a liquid at about 2625 degrees Fahr. (1440 degrees Cent.) Fig. 1 shows an alloy of 30 per cent molybdenum quenched from just above 1440 degrees Cent. at which temperature liquid was visible on the surface of the metal. The eutectic is easily recognized at the grain boundary and bordering it. This finely meshed appearance is typical of this eutectic rapidly cooled as was shown by Fig. 6 in the writer's earlier paper. Certain peculiar characteristics in shape and arrangement of the phases in this range of composition might easily lead to erroneous conclusions unless the microstructures have been observed after a rather large variety of heat treatments. For example the presence of a small amount of eutectic will strongly promote the precipitation of the compound from the solid solution even with very rapid cooling. In Fig. 2 this 30 per cent molybdenum alloy has been cooled from the melt at 2820 degrees Fahr. (1550 degrees Cent.) to a black heat in one minute. Along with the normal quantity of eutectic is present some solid solution from which small plates of the compound have precipitated in the solid.

Contrast with this, the structure shown in Fig. 3 which is a 20 per cent molybdenum alloy containing no eutectic and cooled from the melt at 2820 degrees Fahr. (1550 degrees Cent.) to a black heat in 5 minutes. Note that in this case and even with a moderate cooling rate the precipitation is very scant in the grain boundary and adjoining it.

As the authors aptly state, the compound readily agglomerates or "spheroidizes" with brief heating at temperatures of 1830 degrees Fahr. (1000 degrees Cent.) and above. In Fig. 4 the compound is shown in three forms. The finely laminated eutectic was formed during freezing and preserved along with solid solution by quenching from 2605 degrees Fahr. (1430 degrees Cent.) Upon reheating to 1000 degrees Cent. for 2 hours some of the compound in the eutectic agglomerated to form the massive particles seen in the center of the field. The heating at 1000 degrees Cent. has resulted also in a precipitation of compound from the solid solution which

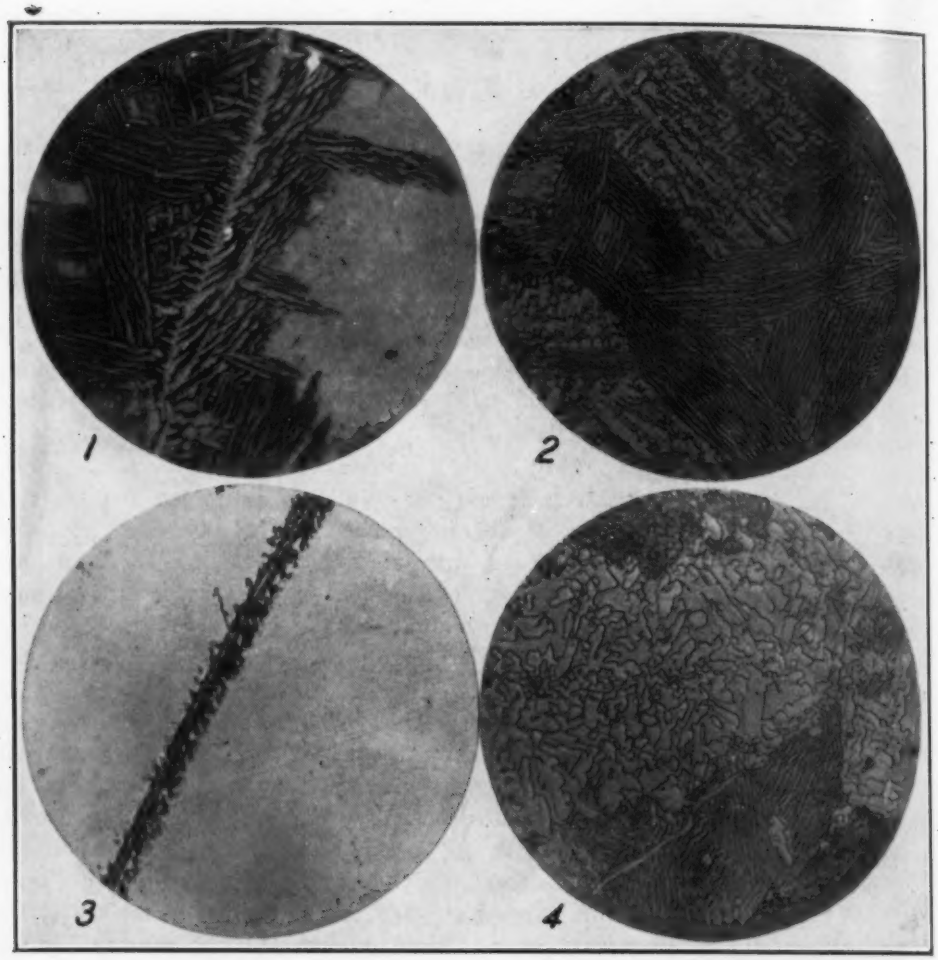

Fig. 1—Photomicrograph of Fe + 30 Per Cent Mo, Quenched from 1450 Degrees Cent. × 1000. Fig. 2—Fe + 30 Per Cent Mo, Cooled from Melt at 1550 Degrees Cent. to Black in 1 Minute. × 500. Fig. 3—Fe + 20 Per Cent Mo, Cooled from Melt at 1550 Degrees Cent. to Black in 5 Minutes. × 500. Fig. 4—Fe + 30 Per Cent Mo, Cooled from 1475 to 1430 Degrees Cent. in 3 Minutes. Quenched 1430 Degrees Cent. Reheated at 1000 Degrees Cent. 2 Hours. × 500.

being rather finely dispersed appears in this photomicrograph as darkened areas at the edges of the field.

As previously stated, at the composition 36 per cent molybdenum the alloy is composed entirely of the eutectic. As the molybdenum content is increased above 36 per cent the liquidus temperature or the temperature necessary to completely fuse the alloy rises rapidly so that at 45 per cent molybdenum the alloy to be completely fused must be heated to about 2770 degrees Fahr. (1520 degrees Cent.) Fig. 5 shows such an alloy heated at 2730 degrees Fahr. (1500 degrees Cent.) for 1 hour and cooled to black heat in 1 minute. Note in the upper portion the perfectly formed dendrites of Fe_2Mo_2 which obviously crystallized from a liquid. In the lower portion of the field (and melt) remain massive areas of unfused metal surrounded by the eutectic which occupies the position of the continuous liquid phase

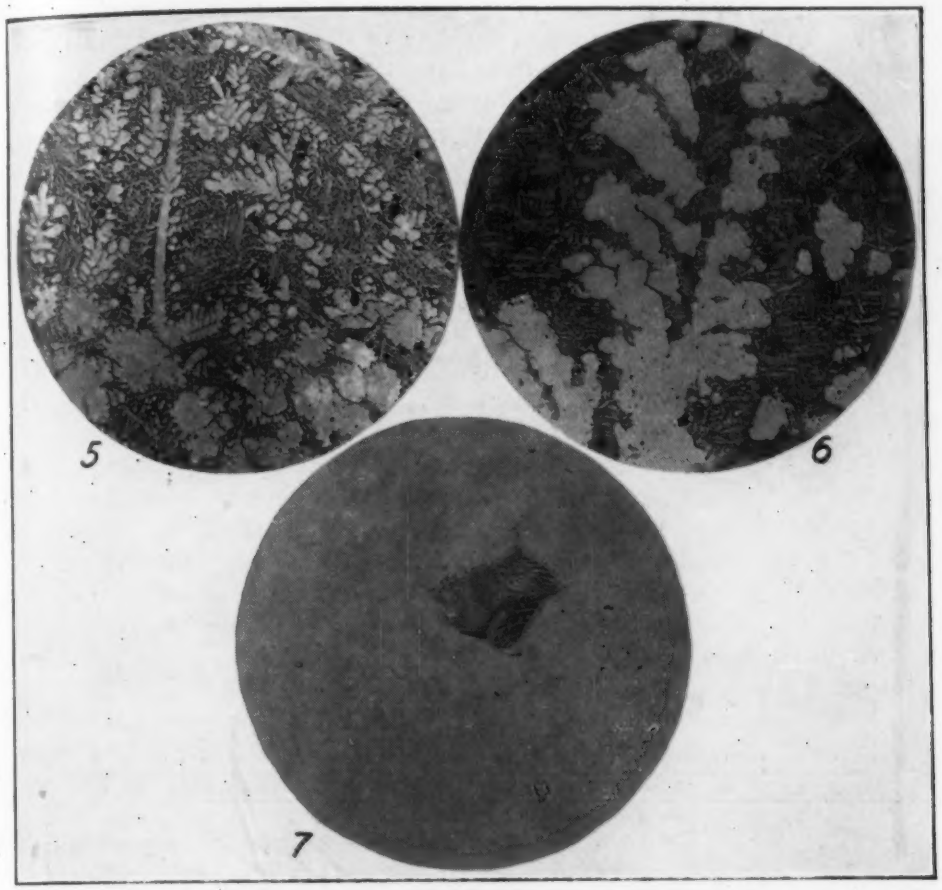

Fig. 5—Photomicrograph of Fe + 40 Per Cent Mo, Cooled from 1500 Degrees Cent. to Black in 1 Minute, Shows Incomplete Fusion. × 75. Fig. 6—Fe + 45 Per Cent Mo, Cooled from 1600 to 1430 Degrees Cent. in 15 Minutes. Quenched. × 100. Fig. 7—Fe + 53 Per Cent Mo, Heated 1400 to 1450 Degrees Cent. 12 Hours. Cooled to 1430 Degrees Cent. and Held 1425 to 1435 Degrees Cent. 1 Hour. × 500.

present at 2730 degrees Fahr. (1500 degrees Cent.) After heating at 2785 degrees Fahr. (1530 degrees Cent.) the melt after rapid cooling consists throughout of the freely formed dendrites surrounded by eutectic. Incidently it might be mentioned that this procedure furnishes a most convenient and reliable method for the determination of the liquidus temperature in this type of alloy. Referring to Fig. 5 it is obvious that the unmelted portions are rich in molybdenum and consequently the upper portions of the melt contain much less molybdenum than the intended composition of the alloy. In fact there may be present regions which upon quenching from just below the solidus temperature will consist of solid solution alone.

The figures for solid solubility of molybdenum in iron as given in Fig. 3 by the authors of this paper I am at loss to explain except by assuming that the specimens with which they worked were not true "melts", and consequently contained portions considerably lower in molyb-

denum content than the supposed composition of the alloy. These dendrites of compound appear in increasing quantity as the molybdenum content rises above 36 per cent. Fig. 6 shows these dendrites with eutectic in a 45 per cent molybdenum alloy. At the composition 53 per cent molybdenum, this alloy containing 0.5 per cent less molybdenum than the compound formula Fe_3Mo_2 requires, the eutectic still persists. Such an area, with its typical structure

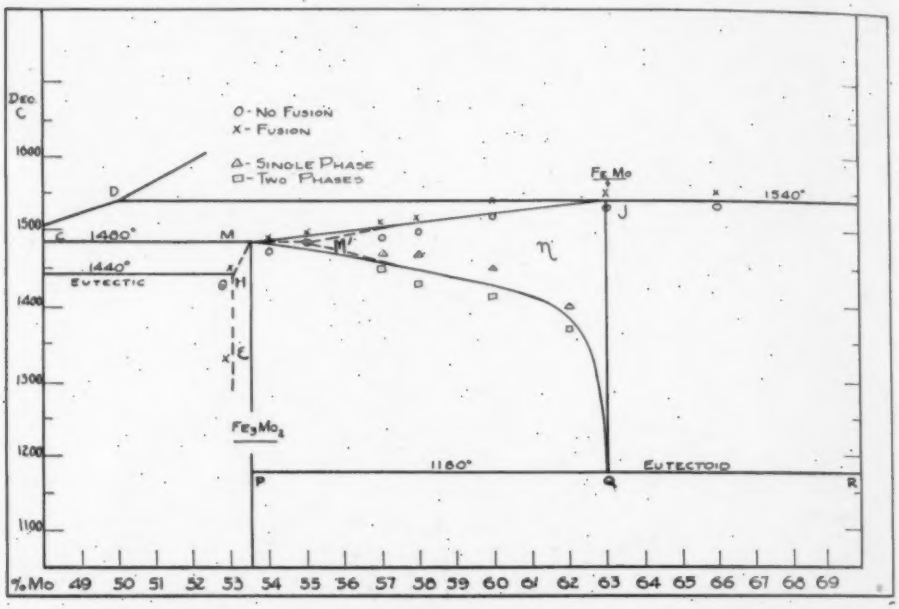

Fig. 8—Portion of the Iron-Molybdenum Equilibrium Diagram.

is shown in Fig 7. Even after long soaking in the region of 2550 degrees Fahr. (1400 degrees Cent.) a small but easily detectable amount of liquid forms upon reheating to 2625 degrees Fahr. (1440 degrees Cent.)

Thus it appears that the solubility of iron in the compound Fe_3Mo_2 is less than 0.5 per cent and the area designated by epsilon should be narrowed from 2 or 3 per cent to not more than 0.5 per cent. While it is quite possible that a small amount of iron is soluble in the compound Fe_3Mo_2 the evidence furnished by the analysis of the isolated compound as described on page 352, would scarcely seem to warrant the state of affairs indicated in the diagram Fig. 2. The solidus line ON is obviously drawn for convenience to illustrate a presumed condition. On the basis of actual temperature observations and microscopic examinations this line could with more justice be drawn as shown in Fig. 8, a diagram of this range of composition drawn from the temperature determinations indicated thereon.

The phase designated in this paper as eta (η) and the eutectoid into which it transforms are fully confirmed by a rather detailed study of this composition range. The authors are to be complimented upon this extremely interesting addition to the equilibrium diagram of the system.

There are certain features of microstructure exhibited by the alloys in

this range which are not described in the paper and which are worthy of study.

Between 53 and 55 per cent molybdenum there is a detectable rise in the solidus temperatures, from 2625 to 2695 degrees Fahr. (1440 to 1480 degrees Cent.) The 55 per cent molybdenum composition shows the first formation of a liquid phase at a temperature definitely higher than the 54 per cent. The rise in the solidus temperature continues quite uniformly until the molybdenum content reaches about 63 per cent. Between 63 and 89 per cent molybdenum the first liquid appears at 2805 degrees Fahr. (1540 degrees Cent.), i. e. the temperature of the peritectic reaction.

The phase eta is easily recognized in alloys containing between 55 and 63 per cent molybdenum when quenched from above the line MQ in Fig. 8. Fig. 9 shows the structure typical of this phase. The authors show a micrograph in their Fig. 25 of such a specimen with a somewhat different surface appearance. The apparent grain boundaries here shown are very suggestive of cracks in the surface film of oxide formed when these alloys are etched with potassium ferricyanide. When this brown film of oxide is removed as in Fig. 10 there is found to be no connection between the cracks of the oxide film and the true grain boundaries in the metal which are developed by an acid etch.

When alloys of molybdenum content between 55 and 63 per cent are cooled through the temperatures indicated by the line MQ (Fig. 8) a second phase forms at the grain boundaries and within the eta grains apparently along crystallographic planes, as shown in Fig. 11. If the temperature falls below about 1200 degrees Cent. the remaining areas of the eta grains are darkened and marked by striatious or parallel bands alternately light and dark. (Fig. 12.) As the molybdenum concentration approaches 63 per cent this darkening becomes more intense and with sufficiently slow cooling through the range between 2190 and 2100 degrees Fahr. (1200 and 1150 degrees Cent.) a general darkening of the eta phase takes place which has the appearance of a true eutectoid. Figs. 13 and 14.

A measurable volume shrinkage appears to accompany this change. On several blocks of the 64 per cent molybdenum alloy measured as quenched from 2730 degrees Fahr. (1500 degrees Cent.) and again after slowly cooling through 2100 degrees Fahr. (1150 degrees Cent.) the dimensions after the latter treatment had decreased by 0.2 to 0.3 per cent. The structures in this range resemble in some respects those found in the hypoeutectoid steels. The reactions are however much more sluggish, both in the rejection of the proeutectoid phase and in the formation of the true eutectoid structure.

The writer is inclined to believe that the eta phase begins at a composition near to 53.4 per cent molybdenum, that of the Fe_2Mo_2 compound. Its presence is indicated at 54 per cent molybdenum. This conclusion is based upon the unmistakable rise in the solidus temperature at between 54 and 55 per cent molybdenum as well as upon the structure shown in Fig. 15. This alloy of 54 per cent molybdenum was quenched from 2715 degrees Fahr. (1490 degrees Cent.) and shows that some liquid was present

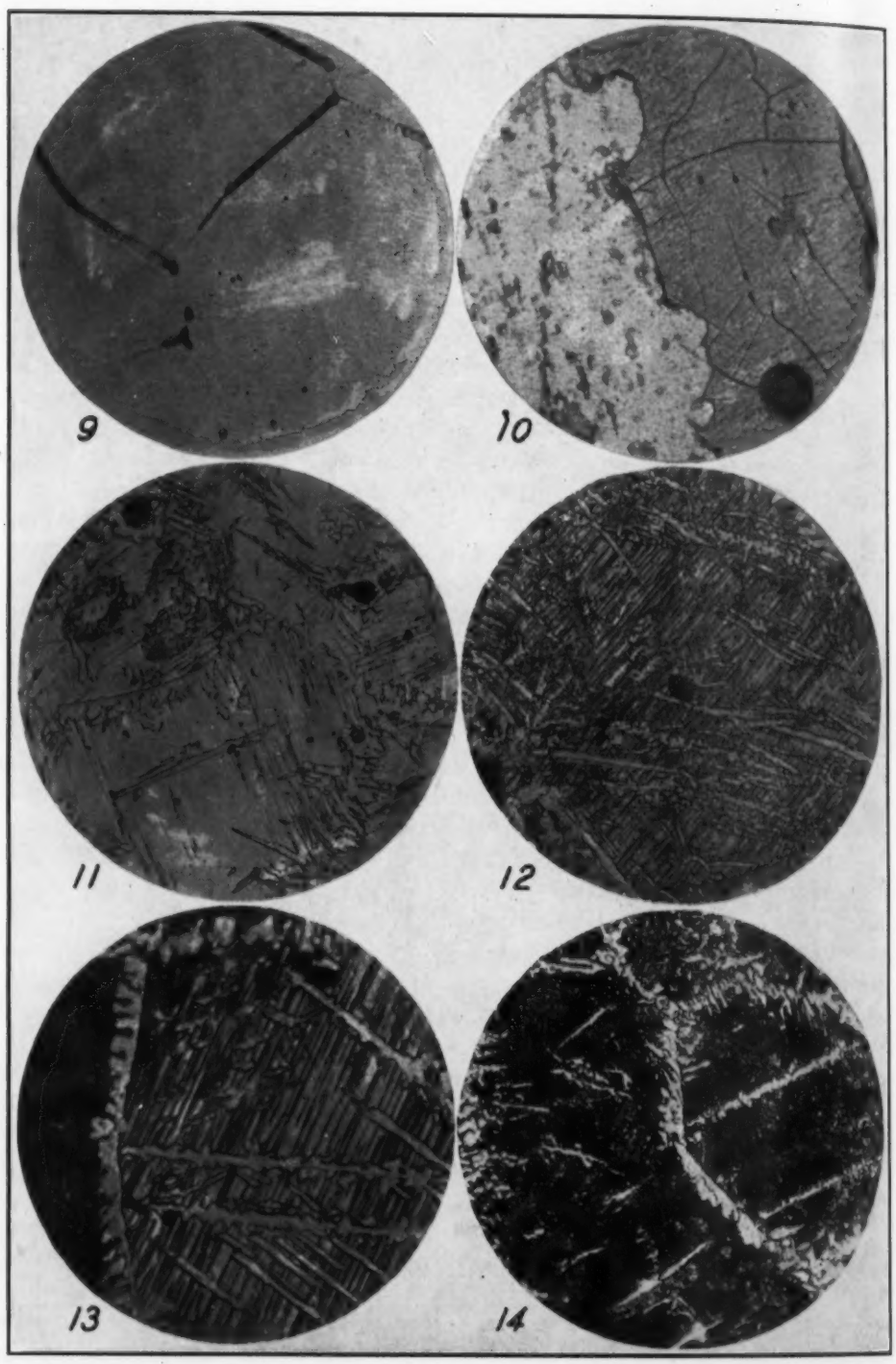

Fig. 9—Photomicrograph of Fe + 62 Per Cent Mo, Quenched from 1450 Degrees Cent. Etched H_2SO_4 + HNO_3. Fig. 10—Fe + 60 Per Cent Mo, Quenched from 1500 Degrees Cent. Surface Partially Covered by Oxide Film Formed in Etching with Potassium Ferricyanide. Fig. 11—Fe + 60 Per Cent Mo, Cooled from 1475 to 1250 Degrees Cent. in 15 Minutes. Quenched. Etched H_2SO_4 + HNO_3. × 500. Fig. 12—Fe + 60 Per Cent Mo, Cooled from 1475 to 1100 Degrees Cent. in 45 Minutes. Quenched. × 500. Fig. 13—Fe + 62 Per Cent Mo, Cooled from 1450 to 1100 Degrees Cent. in 30 Minutes. Held at 1100 Degrees Cent. 30 Minutes. Quenched. × 1000. Fig. 14—Fe + 62 Per Cent Mo, Cooled 1450 to 1100 Degrees Cent. in 30 Minutes. Held at 1100 Degrees Cent. 2 Hours. Quenched. × 500.

at the time of quenching. The solid material is marked by narrow and irregular banded areas very suggestive of the formation of a new phase during the quench. The speed of formation of the left hand phase along the line MQ decreases rapidly with increase in molybdenum content. Hence at the composition of 54 per cent molybdenum we might hardly expect to retain the eta phase even by very rapid cooling. In the absence of certain experimental evidence it may reasonably be assumed that the peritectic reaction at 2695 degrees Fahr. (1480 degrees Cent.) does not go to completion and that the line CM should be extended to M′ at 55 per cent molybdenum. This condition is represented in Fig. 8 by the dashed lines.

At about 63 per cent molybdenum the alloy after cooling very slowly to 2100 degrees Fahr. (1150 degrees Cent.) is composed entirely of the eutectoid. The boundary line JQ of this phase appears to be truly vertical, for when the next phase on the right, the molybdenum-rich solid solution, appears at 64 per cent it seems to be unchanged in quantity regardless of cooling rate. Thus the limiting composition of the eta phase appears to approximate that of the compound FeMo calling for 63.2 per cent molybdenum, and the region between the two compounds may be considered to be occupied by two phases, the compound Fe_2Mo_2 and the eta phase, a solid solution of iron in the compound FeMo. As the alloy is cooled the eta phase, by precipitating iron in the form of Fe_2Mo_2, changes its composition along the line MQ and at about 2155 degrees Fahr. (1180 degrees Cent.) changes to an eutectoid of Fe_2Mo_2 and the molybdenum-rich solid solution dissolving about 8 per cent of iron.

Since it is impossible to completely melt an alloy of 60 per cent molybdenum below 3270 degrees Fahr. (1800 degrees Cent.) the factor of nonuniformity in composition takes on added importance in interpreting the structures formed in this range of the system. A specimen which has been largely molten may yield a structure in which the segregations of molybdenum-rich material cannot be eliminated by diffusion even by prolonged heating at a temperature just below the solidus. In such a case the eutectoid will first assume its typical appearance in the regions immediately surrounding the molybdenum-rich phase. In the iron-rich areas the eta phase will remain unchanged except for precipitation of Fe_2Mo_2 at the grain boundaries. Fig. 16 shows such a range in composition within a small field. Here is seen in addition the striated appearance developed in regions of intermediate molybdenum concentration.

To best produce homogeneous alloys in this range of composition the pressed metal powders are heated for 15 or 20 hours at 2550 to 2640 degrees Fahr. (1400 to 1450 degrees Cent.) The temperature is then raised to slightly above the solidus for say 15 minutes and then very slowly lowered again to 2640 degrees Fahr. (1450 degrees Cent.) and held for several hours. While the texture of the alloy so formed is somewhat spongy and not well adapted to photomicrography the composition as indicated by microstructure is quite uniform. The similarity in microstructure between these alloys and the hypoeutectoid steels suggested the possibility of marked difference in atomic arrangement between the eta phase and the phases adjoining it.

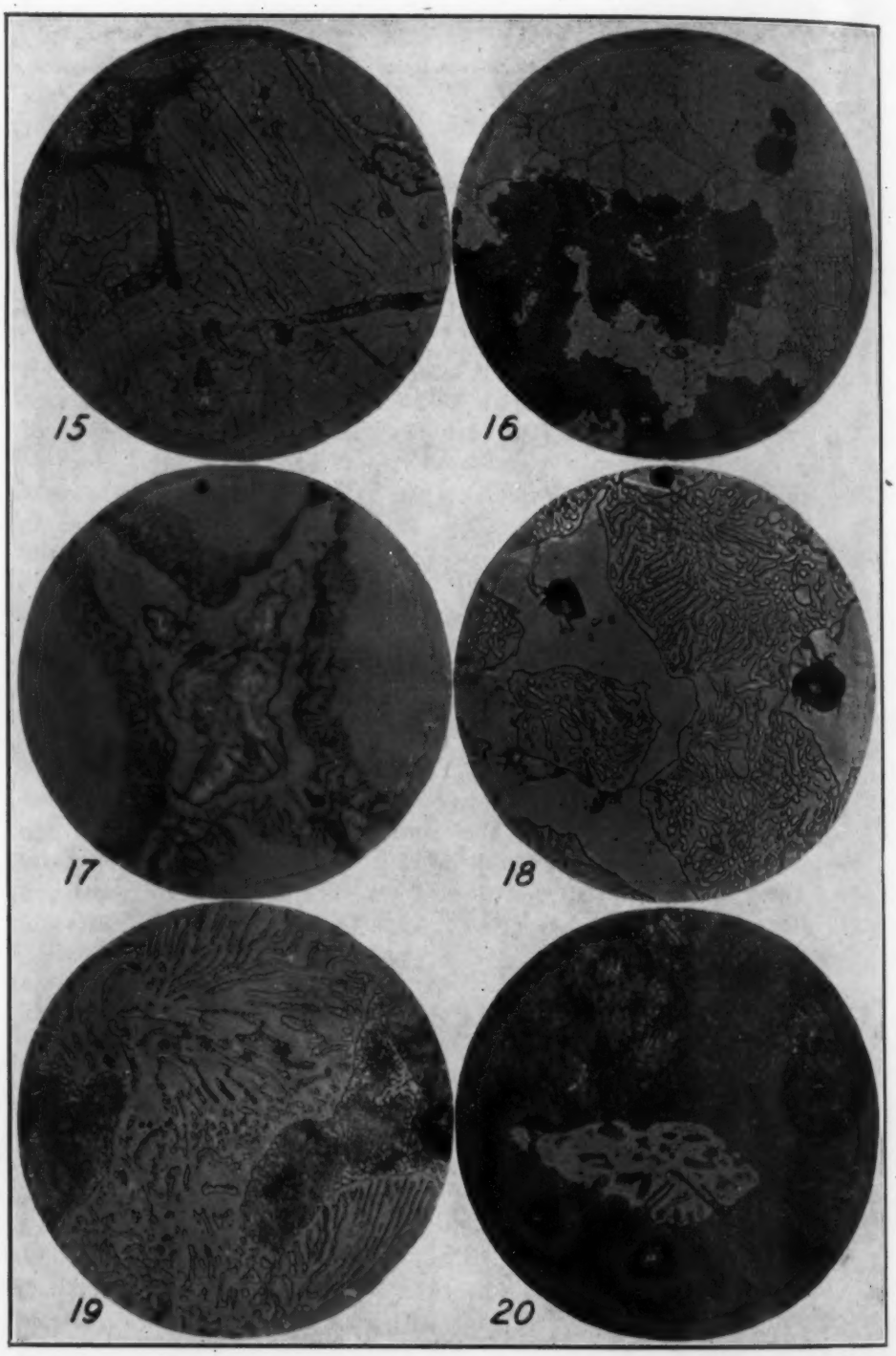

Fig. 15—Photomicrograph of Fe + 54 Per Cent Mo, Quenched from 1490 Degrees Cent. × 500. Fig. 16—Fe + 63 Per Cent Mo, Formed by Partial Fusion at 1750 Degrees Cent. Held 1450 to 1500 Degrees Cent. for 15 Hours. Cooled to 1000 Degrees Cent. in 1 Hour. Quenched. × 200. Fig. 17—Fe + 80 Per Cent Mo, Quenched from 1750 Degrees Cent. × 1000. Fig. 18—Fe + 80 Per Cent Mo, Cooled from 1750 to 1300 Degrees Cent. in 10 Minutes. Quenched. × 500. Fig. 19—Fe + 80 Per Cent Mo, Cooled from 1750 Degrees Cent. to 1350 Degrees Cent. in 1 Hour. From 1350 to 1150 Degrees Cent. in 1 Hour. Quenched. × 500. Fig. 20—Fe + 68 Per Cent Mo, Cooled from 1750 to 1525 Degrees Cent. in 1 Hour. Held at 1525 Degrees Cent. for 2 Hours. Cooled to 1100 Degrees Cent. in 1 Hour. Quenched. × 500.

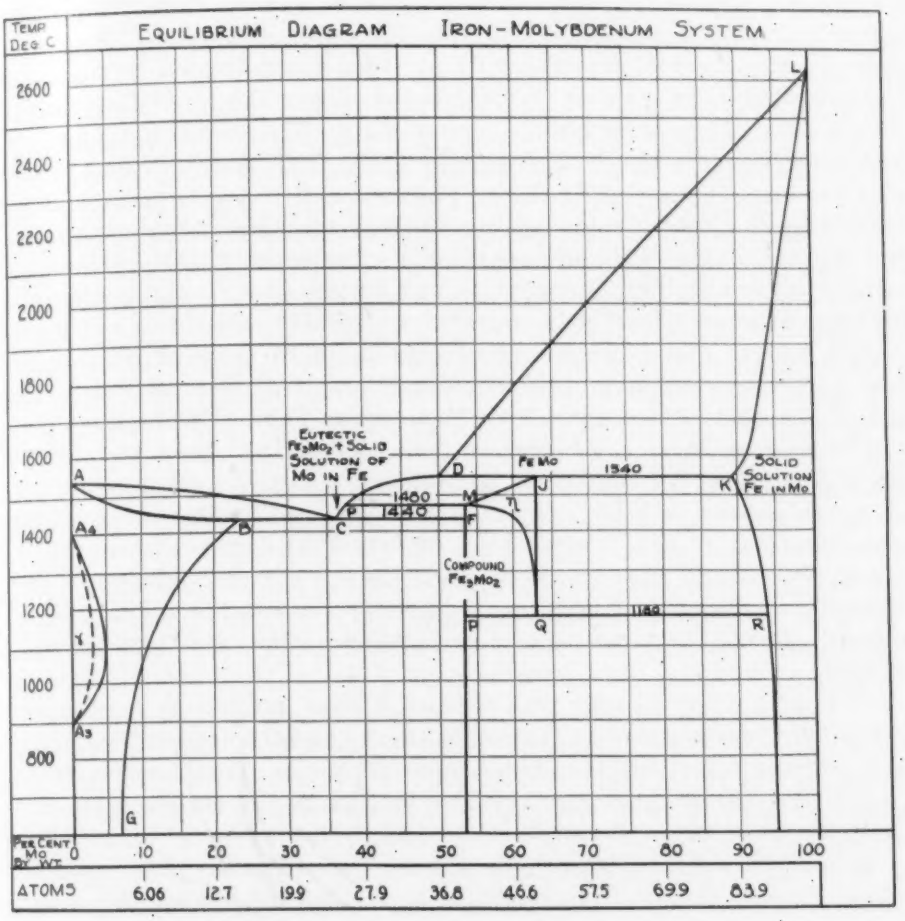

Fig. 21—Equilibrium Diagram of the Iron-Molybdenum System.

The X-ray diffraction patterns of a series of alloys in the range between 50 and 64 per cent molybdenum have been obtained by Miss Chartkoff at the Cleveland Wire Works' Laboratory. They form a part of a series of the iron-molybdenum system which is as yet not quite completed. X-ray spectra of the alloys in the range mentioned show no detectable difference in lattice between 53 per cent and 63 per cent molybdenum as quenched from the region MJQ. The spectra of alloys in this composition range are typified by several groups of lines indicating a crystal system of low symmetry.

Alloys quenched from above the line MQ, however, always yield the spectrum characteristic of a coarse-grained material, while slow cooling through this temperature range results in a diffraction pattern typical of a relatively fine-grained metal. In alloys cooled below the eutectoid temperature the lines of the molybdenum-rich phase in the eutectoid begin to appear as the molybdenum content approaches 63 per cent. Thus it appears that while the microstructure shows two compounds existing in this series

as distinct phases they differ but slightly in atomic spacing. The authors discuss a second eutectoid formed near 2820 degrees Fahr. (1550 degrees Cent.) in alloys containing about 90 per cent molybdenum. By assuming this eutectoid they explain the darkened finger-like precipitate which appears as a fringe around the edges of the molybdenum-rich phase when quickly cooled from above 2820 degrees Fahr. (1550 degrees Cent.) These zones are distinctly a part of the molybdenum-rich phase, however, and are only produced by very rapid cooling through the temperature range near 2805 degrees Fahr. (1540 degrees Cent.) Furthermore this phenomenon exists in all compositions between 64 and 89 per cent molybdenum and is quite absent when the alloy is cooled at a moderate rate through this temperature range. Fig. 17 shows this fringe in an 80 per cent molybdenum alloy water-quenched from 3180 degrees Fahr. (1750 degrees Cent.) The same alloy cooled in 10 minutes from 3180 degrees Fahr. (1750 degrees Cent.) to 2370 degrees Fahr. (1300 degrees Cent.) (Fig. 18) shows no traces of such a formation, but rather the normal precipitate the eta phase within the molybdenum-rich solid solution due to a decrease in solid solubility as the temperature was lowered from 2805 to 2370 degrees Fahr. (1540 to 1300 degrees Cent.) This fringe of precipitate is obviously the result of a metastable condition and with no evidence to warrant the addition of the proposed eutectoid or to necessitate any further explanation than the writer originally offered.

It is of interest to note that the particles of precipitate from molybdenum-rich phase undergo the eutectoid change at 2155 degrees Fahr. (1180 degrees Cent.) along with the excess of the eta phase. This change is shown in an incomplete state in Fig. 19 while in Fig. 20 the eutectoid has completely formed.

Below 2155 degrees Fahr. (1180 degrees Cent.) the eta phase must precipitate directly from the molybdenum-rich solid solution as the authors state. Finally in Fig. 21 is presented the complete diagram of the system based on the evidence now available.

The general similarity in form between the iron-molybdenum and iron-tungsten systems suggested the probable occurrence in the latter system of a corresponding eta phase and an eutectoid transformation.

A careful exploration of the iron-tungsten system in the region of composition between 70 and 90 per cent tungsten with a view to detecting such features results in no indication of their presence.

It appears that the iron atom is able to replace the molybdenum atom to a considerable extent and especially at elevated temperatures. This fact is indicated by the molybdenum-rich solid solution dissolving some 18 per cent by atoms of iron at 2730 degrees Fahr. (1500 degrees Cent.), and also by the existence of the eta solid solution.

In the iron-tungsten system, however, we find that about 3 per cent by atoms of iron saturate the tungsten at 2910 degrees Fahr. (1600 degrees Cent.) The very low solubility of iron in tungsten may be reflected in the absence of a second solid solution corresponding to the eta phase in the iron-molybdenum alloy system.

Authors' Reply to Written Discussion

We are indebted to Mr. Sykes for his re-examination of our results and confirmation of the existence of the eta-phase found by us with the detailed study of its existing ranges of composition, but regarding the following matters, we regret to say that we are not agreed with his view.

Concerning the question of the saturation point of the alpha-phase in the eutectic temperature and the solid solubility curve BY, we believe that the experimental results are better represented by our diagram (Fig. 2 or 3) than by Mr. Sykes'; that is the saturation point of the alpha-phase is above 30 per cent molybdenum, and the eutectic horizontal does not extend to 23 per cent molybdenum, as in his diagram (Fig. 8). He infers that the eutectic exists between 23 to 53 per cent molybdenum, since alloys in these composition ranges contain a typical eutectic structure, showing finely meshed appearance as in Fig. 1, if quenched from just above 2625 degrees Fahr. (1440 degrees Cent.) But we have obtained the similar structure by rather less rapid quenching from a temperature at which the alloy consists of a single alpha-phase, and if the same alloy is quickly quenched from a partially molten state, a somewhat different structure is obtained as stated below. Consequently it is concluded that the meshed appearance or acicular crystal in Fig. 1 may be the epsilon-phase or compound Fe_3Mo_2 separated along the cleavage of the alpha-phase during quenching, owing to the fact that the rate of cooling is not sufficiently quick to suppress the separation of the epsilon-phase.

Fig. A shows the structure of an alloy containing 29.7 per cent molybdenum, well annealed at 2550 degrees Fahr. (1400 degrees Cent.) and quickly quenched into ice water. The alloy shows the polygonal structure indicating that the specimen consists of a single alpha-phase at 2550 degrees Fahr. (1400 degrees Cent.) If, however, the specimen is air-cooled from the same temperature for about 10 seconds and then quenched in the molten tin, a different structure is obtained, as shown in Fig. B. The structure is quite similar as in Fig. 1 obtained by Mr. Sykes. The acicular structure consists of the epsilon-phase separated from the alpha-solid solution during cooling, owing to the rather slow quenching rate.

Figs. C and D show the structure of the same alloy quenched in water from about 2660 and 2695 degrees Fahr. (1460 and 1480 degrees Cent.) respectively. The white part is the alpha-phase and the dark part is of the same nature as the dark part in Fig. B, though it is finer, and shows that this part was melted before the quenching, as the quenching temperature was above the eutectic temperature. The white dendritic globules in the dark part in Fig. D are the alpha-phase separated from the melt during quenching. The fact that the dark area in Fig. D is larger than in Fig. C shows that much melt existed before quenching. Comparing these structures, Figs. C and D with Fig. B, we can easily recognize the difference between the structure of an alloy quenched from a partially molten state and that quenched after completely solidified, though the same change, i. e. deposition of the epsilon-phase, takes place during quenching.

Thus we can decidedly conclude that the alloy containing 29.7 per cent

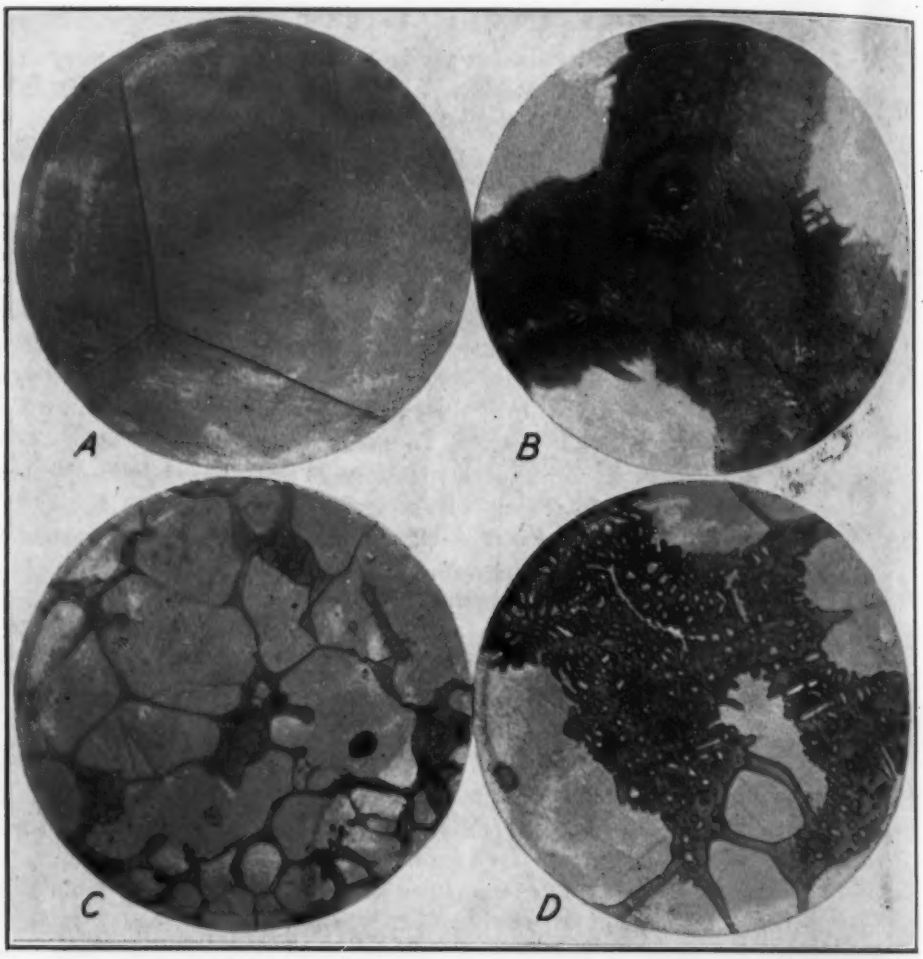

Fig. A—Photomicrograph of Specimen Containing 29.7 Per Cent Mo. Quickly Quenched into Ice-Water at 1400 Degrees Cent. × 200. Fig. B—Photomicrograph of Specimen Containing 29.7 Per Cent Mo. Air Cooled from 1400 Degrees Cent. for 10 Seconds, and then Quenched into Molten Tin. × 200. Fig. C—Photomicrograph of Specimen Containing 29.7 Per Cent Mo. Quenched at About 1460 Degrees Cent. into Ice-Water. × 100. Fig. D—Photomicrograph of Specimen Containing 29.7 Per Cent Mo. Quenched at about 1480 Degrees Cent. into Ice-Water. × 100.

molybdenum forms a homogeneous alpha solid solution at 2550 degrees Fahr. (1400 degrees Cent.) and no eutectic is formed.

The eutectic structure is not observable in the quenched alloy unless the molybdenum content exceeds 36 per cent. The eutectic structure is very confusing, for it consists mainly of the alpha-phase, from which the epsilon-phase partially precipitates during quenching and thus the proper structure is destroyed, unless the rate of quenching is sufficiently high.

From the data described in the paper, we believe that the solubility curve of the epsilon-phase in the alpha solid solution is rapidly decreased as the temperature decreases as shown in Fig. 2 or 3, curve BY. Mr. Sykes doubts that our specimens were true melts and that the molybdenum content might be less than the supposed composition of the alloys, but our speci-

mens of these composition ranges were completely melted and were cast in an iron mold, and hence no segregation is recognized; moreover, the molybdenum content in the alloys was determined by careful analysis.

As to the solubility of the alpha-phase in the epsilon-phase, or the composition range of the epsilon-phase, we cannot agree with Mr. Sykes' view that the solubility is less than 0.5 per cent. According to the result of our experiment, an alloy with 49.9 per cent molybdenum consists of homogeneous epsilon-phase at the room temperature, as shown in Fig. 19 and the result of analysis of the isolated epsilon-phase is 50.5 per cent molybdenum (page 352) which is 3.5 per cent less molybdenum than the compound Fe_2Mo_3. Consequently the solubility range of about 3 per cent at the room temperature is recognized, though the change of solubility with the temperature rise is not studied.

We are much pleased with Mr. Sykes' detailed study on the composition ranges of the eta-phase. The specimen quenched from a temperature above 2190 degrees Fahr. (1200 degrees Cent.) consisting of the eta-phase alone shows a spider-web-like line in a brown colored surface as shown in Fig. 25, when etched with an alkaline solution of potassium ferricyanide. The lines are neither cracks in the surface film of the oxide formed by etching, nor grain boundaries, though their exact nature is unknown.

Regarding a second eutectoid formed near 2820 degrees Fahr. (1550 degrees Cent.) in alloys containing about 90 per cent molybdenum, we could not confirm by thermal data or any physical change. We can, however, observe a structure, similar to the eutectoid in steels, when the molybdenum-rich alloys with 64 to 93 per cent molybdenum are rather quickly cooled from above 2820 degrees Fahr. (1550 degrees Cent.), as shown in Fig. 34 and Fig. 17, and by annealing or slow cooling, it coarsens as shown in Fig. 35 and Fig. 18. It is very improbable that such a structure is formed by only a change of solid solubility, unless a eutectoid change takes place

A STUDY OF BURNING AND OVERHEATING OF STEEL—PART II

By W. E. Jominy

Abstract

This paper is a continuation of the study of overheating of steels. This section covers particularly the forging of steels, after heating in various atmospheres, to determine the limiting temperatures in forging. These experiments were conducted on a series of plain carbon and alloy steels. The results are summarized in a table showing the temperatures at which the various steels investigated will burn if forged immediately after heating in a direct-fired gas furnace when using an excess of gas and air.

IT was the aim of the second part of this investigation to study further the conditions under which steel will burn, and to determine more precisely the temperatures at which burning begins in order to know the limiting temperatures in forging. From the results reported in Part I of this study it was expected that the burning temperature for a given steel would be lower in a turbulent oxidizing atmosphere than in a turbulent reducing one, and consequently tests were made by heating in these atmospheres. In this second part of the investigation all the tests included heating and forging as distinguished from those in Part I in which the steels were not forged after heating.

The general procedure was to heat the furnace to the desired temperature and to secure the desired atmosphere, and then to place the cold sample of steel in the furnace against the platinum cap of the thermocouple tube, described in Part I. The piece was usually kept in the furnace for a total period of 20 minutes, during which time temperature readings were made every minute, and the steel was closely watched for the appearance of molten oxides,

This paper constitutes part of an investigation carried out for the American Gas Association on the subject of forging, at the University of Michigan. Part I appeared in the last issue of Transactions.

The author, W. E. Jominy, member of the society, is associated with the Engineering Research department of the University of Michigan, Ann Arbor, Michigan. Manuscript received March 27, 1929.

sparking and other such phenomena. At the end of the heating period, the steel was removed from the furnace and usually immediately forged with a 12-pound sledge. The forging was done by the upset method, making the sample larger in diameter and shorter in length. After the forging operation, the sample was allowed to cool in the air and then its surface was carefully examined for evidences of burning. The sample was also sectioned and the sections polished and examined under the microscope. The height of the sample was measured before and after forging to record the amount of work done on the piece. Also the number of blows struck to which the piece was subjected were recorded. In the study of each steel all the samples tested were cut from the same bar of steel and were about 1½ inches long.

It was, of course, an easy matter to judge whether the furnace atmosphere was strongly oxidizing or strongly reducing by observing the flame in the furnace. In many cases, however, the furnace atmosphere was analyzed for carbon dioxide, carbon monoxide, and oxygen. When such an analysis was made, the gas sample was withdrawn from the furnace at a point close to the steel specimen after the temperature of the steel specimen had come to equilibrium. The results of the tests were classified according to the steels studied which correspond in chemical composition to specifications S. A. E. 1025, 1045, 1090, 10120, 2320, 3140, and 3250. The chemical analyses of these steels will be found in Table II. These are all widely used steels. They were purchased in bars varying in size from 2 inches round to 2¾ inches square. The results of the tests will be found in Tables III to IX, inclusive.

More than twice as many tests than are listed in these tables have been run in order to check the accuracy of the results. These check tests are omitted for the sake of brevity.

Plain Carbon Steels

S.A.E. 1025 Steel. Except when heated in the muffle furnace, the sample was watched during the heating period to observe the behavior of the steel and to note the temperature and conditions accompanying sparking and melting of the oxide or scale.

Liquid, probably oxide, appeared on the surface of the metal in the oxidizing heats after the metal had been in the furnace about 8 to 10 minutes. The temperature of the piece at the time the

Table II
Chemical Composition of Steels Tested

Steel No.	Type of Steel	Carbon Per Cent	Nickel Per Cent	Chromium Per Cent	Manganese Per Cent	Sulphur Per Cent	Phosphorus Per Cent
8	S.A.E. 1025	0.28			0.57	0.035	0.020
9	S.A.E. 1045	0.47			0.64	0.020	0.022
10	S.A.E. 1090	0.93			0.30	0.016	less than 0.005
11	S.A.E. 10120	1.19			0.29	0.014	less than 0.005
12	S.A.E. 2320	0.24	3.48	0.05	0.60	0.031	0.020
13	S.A.E. 3140	0.43	1.20	0.39	0.54	0.026	0.025
14	S.A.E. 3250	0.52	2.05	0.83	0.53	0.022	0.023

liquid was first observed varied from 2500 to 2560 degrees Fahr. Sparks were also noticed coming off the steel in many of the heats, both in the reducing as well as in the oxidizing atmospheres. In the reducing heats sparks were observed at temperatures of 2650 degrees Fahr. and above, in the oxidizing atmospheres as low as 2545 degrees Fahr. A summary of the tests made with this steel will be found in Table III.

S.A.E. 1045 Steel. Tests were made and recorded as for the 1025 steel and the results of the more important tests, omitting check tests, are listed in Table IV.

As seen from the table, this steel containing 0.47 per cent carbon will burn if heated in a reducing atmosphere to 2625 degrees Fahr. or temperatures above, and it will not burn if heated to 2575 degrees Fahr. and temperatures below. In a turbulent, strongly

Table III
Results of Tests of S.A.E. 1025 Steel Containing 0.28 Per Cent Carbon

Size of Test Specimens—2-inch Diameter by 2 Inches Long

Test No.	Temperature degrees Fahr.	Atmosphere	Mechanical Work Forged with a 12-pound sledge: No. of Blows	Mechanical Work Forged with a 12-pound sledge: per cent reduction in length	Condition of Steel
1	2700	Reducing, turbulent	11		Burned
2	2690	Carburizing, still	15		Not burned
3	2680	Reducing, turbulent	12	27	Burned
4	2675	Reducing, still	8	20	Burned
5	2650*	Reducing, turbulent	19		Not burned
6	2625	Reducing, still	16		Not burned
7	2600	Reducing, still	16		Not burned
8	2610	Oxidizing, turbulent	15		Burned
9	2560	Oxidizing, turbulent	14		Burned
10	2545	Oxidizing, turbulent	12	28.5	Not burned

*A typical analysis of the reducing furnace atmosphere taken at 2650 degrees Fahr. is as follows: CO_2 = 9.4 per cent, CO = 7.6 per cent O = 0 per cent.

Table IV

Results of Tests of S.A.E. 1045 Steel Containing 0.47 Per Cent Carbon

Size of Test Specimens—2¼ Inches Square by 2 Inches Long

Test No.	Temperature degrees Fahr.	Atmosphere	Mechanical Work Forged with a 12-pound sledge: No. of Blows	Mechanical Work Forged with a 12-pound sledge: per cent reduction in length	Condition of Steel
1	2650[1]	Reducing, turbulent	16	24	Burned
2	2625	Reducing, turbulent	16	26	Burned
3	2600	Reducing, turbulent	17	26	Not burned
4	2600[2]	Slightly reducing, nearly neutral turbulent	10	41	Burned
5	2575	Pure carbon dioxide in crucible	16	..	Not burned
6	2570	Reducing, turbulent	18	33	Not burned
7	2570[3]	Oxidizing till piece reached 2440 degrees Fahr., then reducing turbulent	20	..	Not burned
8	2560	Reducing, turbulent	17	21	Not burned
9	2540[4]	Near neutral, turbulent	10	..	Not burned
10	2515	Reducing, turbulent	16	20	Not burned
11	2510	Oxidizing, turbulent	18	33	Burned
12	2505	Oxidizing, turbulent	16	29	Burned
13	2500	Oxidizing, turbulent	15	..	Burned
14	2475	Oxidizing, turbulent	15	20	Not burned
15	2479	Oxidizing, turbulent	..	19	Not burned

[1]Typical analysis of the reducing atmospheres produced is as follows: CO_2 = 10 per cent, CO = 6.47 per cent, O = 0 per cent.

[2]Analysis of the atmosphere produced in this test is as follows: CO_2 = 10.2 per cent, CO = 1.6 per cent, O = 1.0 per cent.

[3]Typical analysis of the oxidizing atmospheres produced is as follows: CO_2 = 9.5 per cent, CO = 0 per cent, O = 5.3 per cent.

[4]Analysis of the reducing atmospheres produced in this test is as follows: CO_2 = 10.4 per cent, CO = 1.6 per cent, O = 0.4 per cent.

oxidizing atmosphere this steel will burn if forged immediately after heating to 2500 degrees Fahr. and will not burn at 2475 degrees Fahr. and temperatures below. In the tests from which these deductions are drawn the atmosphere was either strongly reducing or strongly oxidizing. A typical analysis of the reducing atmospheres is shown in the table.

The question arose as to what would happen in a nearly neutral atmosphere. Several such heats were run, three of which are given in Table IV, test Nos. 4, 5 and 9. In the case of test No. 5, the sample was heated in an atmosphere of pure carbon dioxide to 2575 degrees Fahr. and did not burn. This latter atmosphere was used to similate a neutral furnace atmosphere. It will, of course, differ from a furnace atmosphere in having no moisture or nitrogen content. From these three tests it appears that in a neutral or nearly neutral furnace atmosphere this steel will burn at about the same temperature as in a strongly reducing atmosphere.

To determine whether the lower temperature of burning in the oxidizing atmospheres was due to the action of the gas oxygen, or indirectly to the action of the oxides of iron on the surface formed in the oxidizing atmosphere, a number of tests were made using steel which had been subjected to an oxidizing atmosphere and covered with a heavy scale. One such test is included in Table IV, test No. 7. In this test the sample was heated to 2440 degrees Fahr. in a turbulent, strongly oxidizing atmosphere, then the atmosphere was changed to reducing and the piece heated to 2570 degrees Fahr. and forged. The time in the oxidizing atmosphere was 38 minutes and in the reducing atmosphere 22 minutes. The steel was not burned. Since the temperature to which this steel was heated, 2570 degrees Fahr. was much higher than the temperature at which it will burn in a strongly oxidizing, turbulent atmosphere, it was concluded that the action of the iron oxide on the steel, if any, had no influence on the burning temperature and did not explain the phenomenon of burning at a much lower temperature in oxidizing than in reducing atmospheres.

In the oxidizing tests, liquid, probably oxide, began to show on the steel after it reached 2425 degrees to 2500 degrees Fahr. usually after the steel had been in the furnace 10 or 11 minutes. This liquid, which would usually first be observed on top of the piece, would increase in quantity until it ran over the sides of the steel. In some cases the liquefication occurred at such a rate that it gave the appearance of boiling. In the reducing atmospheres little if any liquid appeared on the test specimens. When it did occur it was at a relatively high temperature, 2575 degrees Fahr. or higher.

Sparks were observed coming off the steel in the reducing atmospheres at temperatures of 2560 degrees Fahr. and above and in the oxidizing atmospheres at temperatures of 2480 degrees Fahr. and above.

S.A.E. 1090 Steel. In Table V are the results obtained on the S.A.E. 1090 steel. This steel will burn at the same temperature in oxidizing as in reducing atmospheres, that is, it will burn at 2425 degrees Fahr. and temperatures above. The only difference obtained between oxidizing and reducing atmospheres was that the oxidizing atmosphere usually produced a more decided burn which more often opened up through the outside surface of the piece, whereas, the reducing atmosphere more often caused burning on

Table V

Results of Tests of S.A.E. 1090 Steel Containing 0.93 Per Cent Carbon

Size of Test Specimens—2¼ Inches Square by 2 Inches Long

Test No.	Temperature degrees Fahr.	Atmosphere	Mechanical Work Forged with a 12-pound sledge No. of Blows	per cent reduction in length	Condition of Steel
1	2520	Carburizing	20	37	Burned
2	2500	Carburizing	3	..	Burned
3	2465	Reducing, turbulent	10	21	Burned
4	2460	Reducing, turbulent	14	..	Burned
5	2425	Reducing, turbulent	17	24	Burned
6	2400	Reducing, turbulent	16	18.5	Not burned
7	2475	Oxidizing, still	8	..	Burned
8	2450	Oxidizing, still	20	..	Burned
9	2425	Oxidizing, turbulent	18	..	Burned
10	2400	Oxidizing, turbulent	16	18.5	Not burned
11	2395	Oxidizing, still	15	..	Not burned

the inside while the outside surface showed no evidence of burning.

It is possible that the lower burning temperature in the oxidizing atmosphere of the lower carbon steels is due to the fact that in such an atmosphere they become hotter than the furnace atmosphere. Under such conditions it might be possible that the steel is actually hotter than the temperature registered by the thermocouple, and that, if the true temperature of the steel were known, it would correspond at the burning point to that at which burning occurs in the reducing atmosphere. Since the reaction which causes the steel to become hotter than the furnace atmosphere starts at 2475 degrees to 2500 degrees Fahr., this effect would be noticed in steels which burn above 2475 degrees Fahr., but not in steels which burn below this temperature. This is actually what has been observed, that is, the steels which burn below 2475 degrees Fahr. such as the S.A.E. 1090 and 10120 steels, show no difference in burning temperatures in the oxidizing and reducing atmospheres, whereas, the steels which burn above 2475 degrees Fahr. as the S.A.E. 1025, 1045, 2320, 3140 and 3250, all show this phenomenon. On the other hand the thermocouple bead is as close to the steel surface as it is possible to get it and still keep the thermocouple from immediate contamination. It should, therefore, register the correct temperature of the sample. Until further advances are made in the science of pyrometry it will probably be impossible to know the real explanation of the relatively low burning temperature in oxidizing atmospheres of the hypoeutectoid steels.

Two tests in Table V are presented to show the results of

Table VI

Results of Tests of S.A.E. 10120 Steel Containing 1.19 Per Cent Carbon

Size of Test Specimens—2 Inches Round by 2 Inches Long

Test No.	Temperature degrees Fahr.	Atmosphere	Mechanical Work Forged with a 12-pound sledge: No. of Blows	Mechanical Work Forged with a 12-pound sledge: per cent reduction in length	Condition of Steel
1	2510	Carburizing, still	22	..	Burned
2	2400	Very reducing, turbulent	16	..	Burned
3	2350	Reducing, turbulent	16	23	Burned
4	2325	Reducing, turbulent	..	..	Not burned
5	2375	Oxidizing, still	20	..	Burned
6	2350	Oxidizing, still	18	..	Burned
7	2320	Oxidizing, still	15	..	Not burned
8	2320	Oxidizing, turbulent	..	14	Not burned

heating in a carburizing atmosphere which was produced with carburizing compound and raw gas. As will be observed both of these samples burned, indicating that a carburizing atmosphere will not protect a 0.93 per cent carbon steel from burning. This confirms the theory that a carburizing atmosphere would prevent a low carbon steel from burning but not a high carbon steel. Liquid oxide appeared on the surface of this steel at temperatures as low as 2475 degrees Fahr. in oxidizing atmospheres and did not appear in the reducing heats.

S.A.E. 10120 Steel. In Table VI are the results of tests made on the S.A.E. 10120 steel. As may be observed from this table, this steel will burn in reducing or oxidizing atmospheres at the same temperature, that is, somewhere between 2320 degrees Fahr. and 2350 degrees Fahr. In a carburizing atmosphere, the steel will burn, as was expected.

Alloy Steels

Three alloy steels were studied. These consisted of an S.A.E. 2320 an S.A.E. 3140 and an S.A.E. 3250 steel. These steels were tested in exactly the same manner as the plain carbon steels already described.

S.A.E. 2320 Steel. The test results on this steel are listed in Table VII. This steel does not burn at 2600 degrees Fahr. but will burn at 2625 degrees Fahr. when heated in a reducing atmosphere. In an oxidizing atmosphere this steel will not burn at 2570 degrees Fahr. but will burn at 2590 degrees Fahr. Liquid oxide

Table VII

Results of Tests of S.A.E. 2320 Steel Containing 0.24 Per Cent Carbon

Size of Test Specimen—2¾ Inches by 1⅜ Inches by 2 Inches Long

Test No.	Temperature degrees Fahr.	Atmosphere	Mechanical Work Forged with a 12-pound sledge No. of Blows	per cent reduction in length	Condition of Steel
1	2650	Reducing, turbulent	20	40	Burned
2	2625	Reducing, turbulent	20	53	Burned
3	2600	Reducing, turbulent	20	50	Not burned
4	2625	Oxidizing, still	20	..	Burned
5	2590	Oxidizing, turbulent	12	62	Burned
6	2570	Oxidizing, turbulent	17	..	Not burned
7	2570	Oxidizing, turbulent	17	..	Not burned

Table VIII

Results of Tests of S.A.E. 3140 Steel Containing 0.43 Per Cent Carbon

Size of Test Specimens—2½ Inches Round by 1½ Inches Long

Test No.	Temperature degrees Fahr.	Atmosphere	Mechanical Work Forged with a 12-pound sledge No. of Blows	per cent reduction in length	Condition of Steel
1	2625	Carburizing	20	..	Not burned
2	2605	Reducing, turbulent	13	17	Burned
3	2590	Reducing, turbulent	18	24	Burned
4	2570	Reducing, turbulent	18	22	Not burned
5	2585	Oxidizing, still	20	..	Burned
6	2550	Oxidizing, turbulent	12	24	Burned
7	2530	Oxidizing, turbulent	19	20	Burned
8	2525	Oxidizing, turbulent	20	22	Burned
9	2500	Oxidizing, turbulent	20	20	Not burned
10	2475	Oxidizing, turbulent	18	20	Not burned

appeared on the surface of the steel at 2525 degrees Fahr. in an oxidizing atmosphere and at 2580 degrees Fahr. in a reducing atmosphere.

S.A.E. 3140 Steel. A summary of the results on this series is shown in Table VIII. This steel will burn in a reducing atmosphere at 2590 degrees Fahr. or temperatures above, and will not burn at 2570 degrees Fahr. or temperatures below. In an oxidizing atmosphere it was found to burn at 2525 degrees Fahr. or temperatures above and not burn at 2500 degrees Fahr. or below.

The steel did not burn at 2625 degrees Fahr. in a carburizing atmosphere. Fig. 9 is a facsimile photograph of a section cut through this sample after forging. There is undoubted evidence of melting on the outside of this specimen which gives it an irregular shape. When this sample was forged the small amount of molten metal on the outside flew in every direction, but the re-

Table IX

Results of Tests of S.A.E. 3250 Steel Containing 0.52 Per Cent Carbon

Size of Test Specimens—2½ Inches Round by 1½ Inches Long

Test No.	Temperature degrees Fahr.	Atmosphere	Mechanical Work Forged with a 12-pound sledge No. of Blows	Mechanical Work Forged with a 12-pound sledge per cent reduction in length	Condition of Steel
1	2605	Reducing, turbulent	19	17	Burned
2	2580	Reducing, turbulent	18	17	Burned
3	2580	Reducing, still	20	..	Burned
4	2550	Reducing, turbulent	18	15	Burned
5	2550	Reducing, turbulent	20	..	Burned
6	2525	Reducing, still	21	..	Not burned
7	2530	Oxidizing, turbulent	18	17	Burned
8	2530	Oxidizing, turbulent	15	..	Burned
9	2500	Oxidizing, turbulent	18	14	Not burned

mainder of the metal remained intact and showed no evidence of burning. This confirms the author's theory that if the metal can be made to melt entirely on the outside in a reducing atmosphere, burning will be avoided.

S.A.E. 3250 Steel. Table IX presents the results in a series of tests on S.A.E. 3250 steel. As will be observed, this steel will burn in a reducing atmosphere at 2550 degrees Fahr. and temperatures above and will not burn at 2525 degrees Fahr. and temperatures below. In a turbulent, oxidizing atmosphere this steel will burn at 2530 degrees Fahr. or temperatures above and will not burn at 2500 degrees Fahr. or temperatures below. There is here very little difference between the temperature of burning in oxidizing and reducing atmospheres. This appears to be true to a modified extent of all the alloy steels tested. With this steel liquid appeared on the surface in oxidizing atmospheres at about 2500 degrees Fahr. and in reducing atmospheres at 2550 degrees Fahr. in smaller quantities.

Discussion of Phenomena Observed

Liquid Oxides. When heated in an oxidizing atmosphere a considerable quantity of liquid was seen on all steels provided the temperature was high enough. In the reducing atmospheres liquid sometimes occurred, although in much smaller quantities and at high temperatures. Oxide could, of course, easily be formed in the reducing atmospheres due to the reaction of water vapor and carbon dioxide on steel. The liquid, it is believed, was oxide of

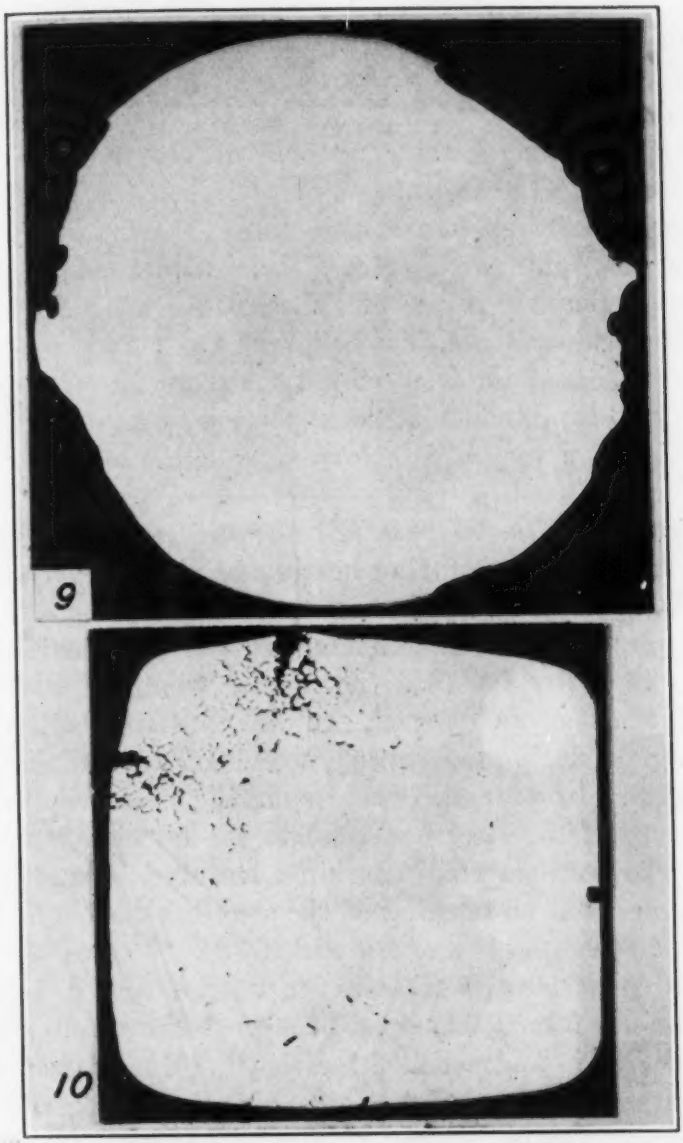

Fig. 9—Facsimile of Section of S. A. E. 3140 Steel Heated to 2625 Degrees Fahr. in a Carburizing Atmosphere and Forged. The Sample was not Burned Although it had Begun to Melt on the Outside.

Fig. 10—Photograph of a Sample of S. A. E. 1045 Steel Heated to 2650 Degrees Fahr. in a Reducing Atmosphere and Forged, then Cut into Four Disks to Show the Extent and Location of the Burned Areas.

iron, although it was observed at lower temperatures than are given for the melting point of the various oxides of iron. According to R. B. Sossman,[9] the melting point of Fe_3O_4 is higher than the melting point of iron his results giving 1580 degrees Cent. (2876

[9]R. B. Sossman, *Journal*, Industrial and Engineering Chemistry, Vol. 8, p. 985, 1916.

degrees Fahr.) According to Tritton and Hanson,[10] the melting point of Fe_2O_3 in contact with iron is 1370 degrees Cent. (2498 degrees Fahr.) In the present study the temperature at which the liquid was first observed on the piece varied considerably. In reducing atmospheres these temperatures were 50 degrees Fahr. and more above the melting point of iron oxide given by Tritton and Hanson, whereas, in oxidizing atmospheres, liquid was observed in some cases at 2375 degrees Fahr. which is about 125 degrees Fahr. lower than the results of Tritton and Hanson. This variation in melting temperatures, it is believed, may be due to variations in the composition of the iron oxide formed under certain conditions. It seems quite apparent that the appearance of liquid on the surface of steel is not a very satisfactory gage of the temperature of that steel.

Sparking. The temperature at which sparks were first seen coming from the steel during heating has been observed for all of the steels. Just what causes these sparks to be given off is not clear. Sparks were given off in reducing as well as in oxidizing atmospheres. In many instances no sparks whatever were given off although the steel was burned. In other instances although sparks were given off during the heating, no evidence of burning was found in the steel. In all cases where sparking occurred, however, the temperature of the steel was close to the burning temperature or above. The freedom from sparking, however, cannot be taken as an assurance that no burning of the steel has occurred.

Extent and Location of Burned Areas. To measure the extent and location of burned areas in steel when heated under certain conditions and forged, a number of steel sections were cut into thin disks and ground and polished for visual and microscopic examination. These disks were cut about $\frac{3}{16}$ inches thick, the cut being made at right angles to the direction of forging. It was observed upon examining these disks that the voids due to burning were rather unevenly distributed through the piece. As a general rule, if steel is burned in an oxidizing atmosphere, the steel surface gives evidence of the burning by breaking open at some point. This happens often when heating in reducing atmospheres also. The preponderance of voids generally seems to be somewhere between $\frac{1}{2}$ and $\frac{2}{3}$ the distance from the center to the edge of the piece.

[10] Loc. cit.

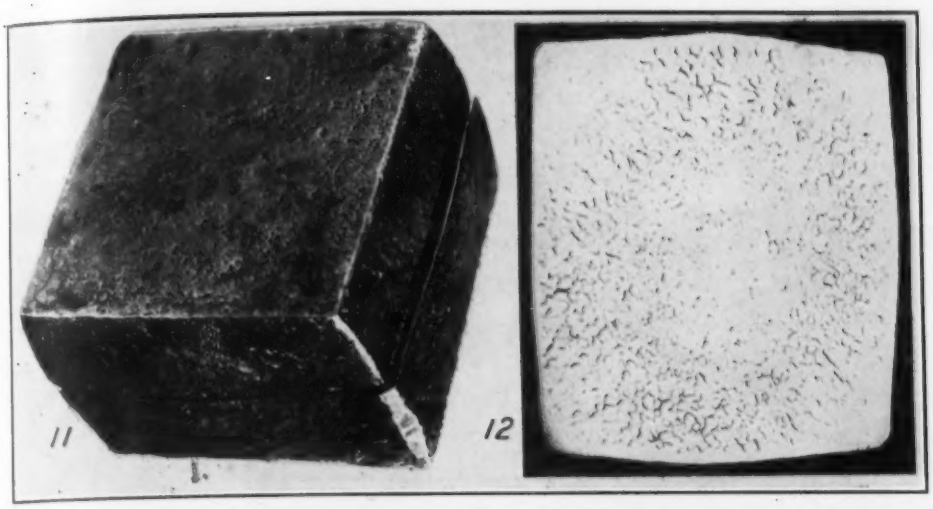

Fig. 11—Fascimile of Sample of S. A. E. 1090 Steel Heated to 2465 Degrees Fahr. in a Reducing Atmosphere and Forged. The Saw Cut Shows where it was Sawed in Half to Examine the Interior Shown in Fig. 12.

Fig. 12—Photograph Showing Interior of Sample Presented in Fig. 11. It is at once Apparent that this Steel is Badly Burned on the Inside.

Fig. 10 shows a disk of S.A.E. 1045 steel after it had been heated to 2650 degrees Fahr. in a reducing atmosphere and forged. This piece had broken open in several places showing unmistakable evidence of burning on the surface. The appearance of these disks is quite characteristic of what is usually found with this type of burning.

Another type of burning which often occurs is that in which the piece burns entirely on the inside. This happens more often when the steel is heated in a reducing than in an oxidizing atmosphere although instances occurring in each type of atmosphere have been observed. Heating just a little above the burning temperature seems to be more apt to result in this type of burning. It is also apt to occur if the steel is held in air for a brief period before striking with the forge hammer. To produce this condition a sample of S.A.E. 1090 steel was heated in a reducing atmosphere to 2465 degrees Fahr. then removed from the furnace and held in the air for ten seconds before forging. The steel gave no indication from its appearance on the outside of being burned, but upon cutting it in half, the inside was found to be burned. Fig. 11, which is a facsimile photograph of the piece, shows the outside appearance of the steel after forging and also the location of the saw cut. Fig. 12 shows the appearance of a polished half section of the steel

after cutting. Examination of this section showed that the steel had been burned. It will be observed, however, that there is an outer rim of metal which is not burned and which accounts for the good appearance of the outside of the forging. It is believed that holding the specimen ten seconds in the air permitted the outside to cool below the burning temperature, whereas, the inside was still above this temperature when struck with the forging sledge. Another factor which aided this type of burning was the decarburization of the outer rim of steel, which raised the burning temperature of this outer rim of steel above that of the steel in the interior of the sample. So far as is known at the present time there is no commercially satisfactory inspection method to detect forgings which have been burned on the inside. It will be evident that this type of burning is dangerous and apt to lead to the failure of such parts in service.

Tests on Forging and Welding Steel After It Has Been Burned

There is lack of agreement among forgemen and metallurgists as to whether a piece of steel that is burned can be forged, and further whether the burned steel can be reclaimed by forging at a welding heat. It is the finding of this investigation that steel which has been burned can be forged and will be found to be fairly malleable when reheated to forging temperature. The voids, however, that have been produced by burning will remain in the steel, and the sample will not be as ductile or malleable as steel which has not been burned. If the burned steel is heated to a welding heat and carefully worked up with the use of welding flux, it can be made to appear sound on the surface and to forge well. Examination of the structure of the steel, however, will show it to contain bands of oxides, which break up the continuity of the microstructure of the steel and result in an inferior material.

A sample of S.A.E. 1025 steel which had been previously badly burned by heating to 2600 degrees Fahr. in an oxidizing atmosphere was reheated in a muffle furnace to a temperature of from 2300 to 2350 degrees Fahr. and forged into a rectangular bar ¾ inches square and 6 inches long. This steel was worked down rather carefully but it forged fairly well from a 2½-inch round sample to a ¾-inch square sample. The surface of the ¾-inch square bar, however, showed it to lack continuity. This may be

Fig. 13—This Photograph Shows a Steel Bar (B) which has been Forged from a Specimen of Burned 0.28 Per Cent Carbon Steel Shown at (A). The Forging Temperature was 2300 Degrees to 2350 Degrees Fahr. Note that the Surface of the Bar Shows Deep Voids and Lack of Continuity.

(C) Photomicrograph of Unetched Sample of Steel after Forging Shown at (B). Note that the Voids Caused by Burning are Still in Evidence.

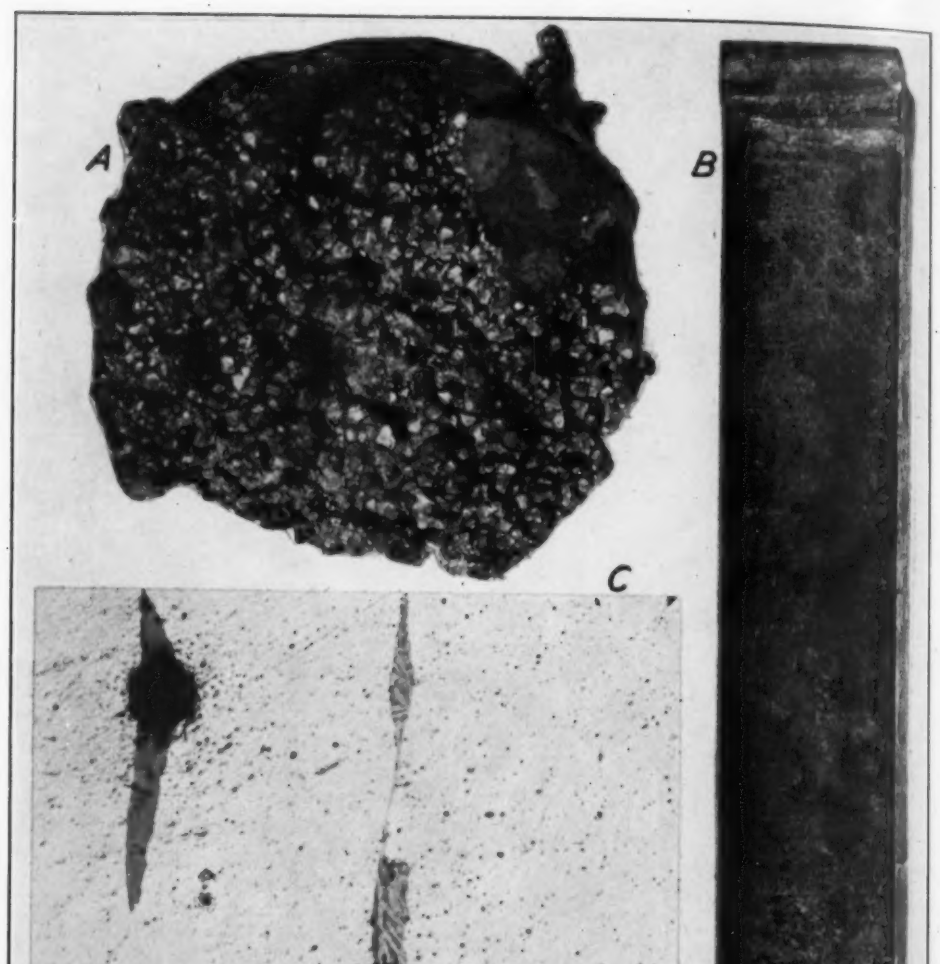

Fig. 14—Photograph Showing a Steel Bar at (B), Forged at a Welding Heat from a Burned Specimen of 0.28 Per Cent Carbon Steel Shown at (A). The Forging Temperature was 2575 to 2600 Degrees Fahr. It will be Observed that the Welded Steel Appears Satisfactory on the Surface.

(C)—Photomicrograph of Unetched Sample of Steel After Welding, Shown at (B). It will be Observed that the Welding Heat has Closed most of the Voids but Oxides are Present in Large Amounts. × 100.

observed in Fig. 13, which shows the burned steel sample before and after forging, also the microstructure of this ¾-inch sample. There can be no doubt that this steel is full of voids and still unsatisfactory after forging.

Another sample of the S.A.E. 1025 steel which had previously been badly burned by heating in a reducing atmosphere at 2700 degrees Fahr. and forged, was studied. This sample was heated in the muffle furnace to 2575 to 2600 degrees Fahr. covered with welding flux, and carefully forged down to a one-inch square bar. After forging this steel appeared on the surface to be entirely satisfactory, as may be seen in Fig. 14, which shows the steel before and after reforging. Examination of the microstructure of this steel, however, shows it to contain a large number of oxides.

The fact that a forging may be burned entirely on the inside without showing any evidence of burning on the surface has been brought out in this paper. When burned in this manner there would be little opportunity for oxidation of the metal at the point of burning since the oxygen or oxidizing gases would have to diffuse through the outer shell of good metal to get to the inside. If such a steel were heated to a welding heat the question naturally occurs whether or not it could be welded and forged to eliminate any trace of the previous burning. If there is a small film of oxide formed around the burned areas, would this not show as oxides in the forged metal?

Tests were made on two samples of the S.A.E. 10120 steel containing 1.19 per cent carbon, burned on the inside. This was done by heating two samples in the muffle furnace to a temperature of 2450 degrees Fahr. then removing from the furnace, holding in the tongs for 10 seconds and forging by the upset method.

Treated in this manner the steel was burned entirely on the inside and gave no evidence whatever of burning on the outside. One of these samples was cut in half, polished and photographed. Photograph, Fig. 15A, shows the inside of this section, giving undoubted evidence of burning, and the shell of good metal on the outside. No cut was made in the other sample so the air could not be admitted to the burned section. This latter sample was reheated to a welding heat in the muffle furnace, the temperature being 2300 degrees Fahr. and forged into a bar about ¾ inch square. It forged satisfactorily. Figs. 15B and C shows this sample before and after forging. The ¾-inch square bar was then cut into sections and

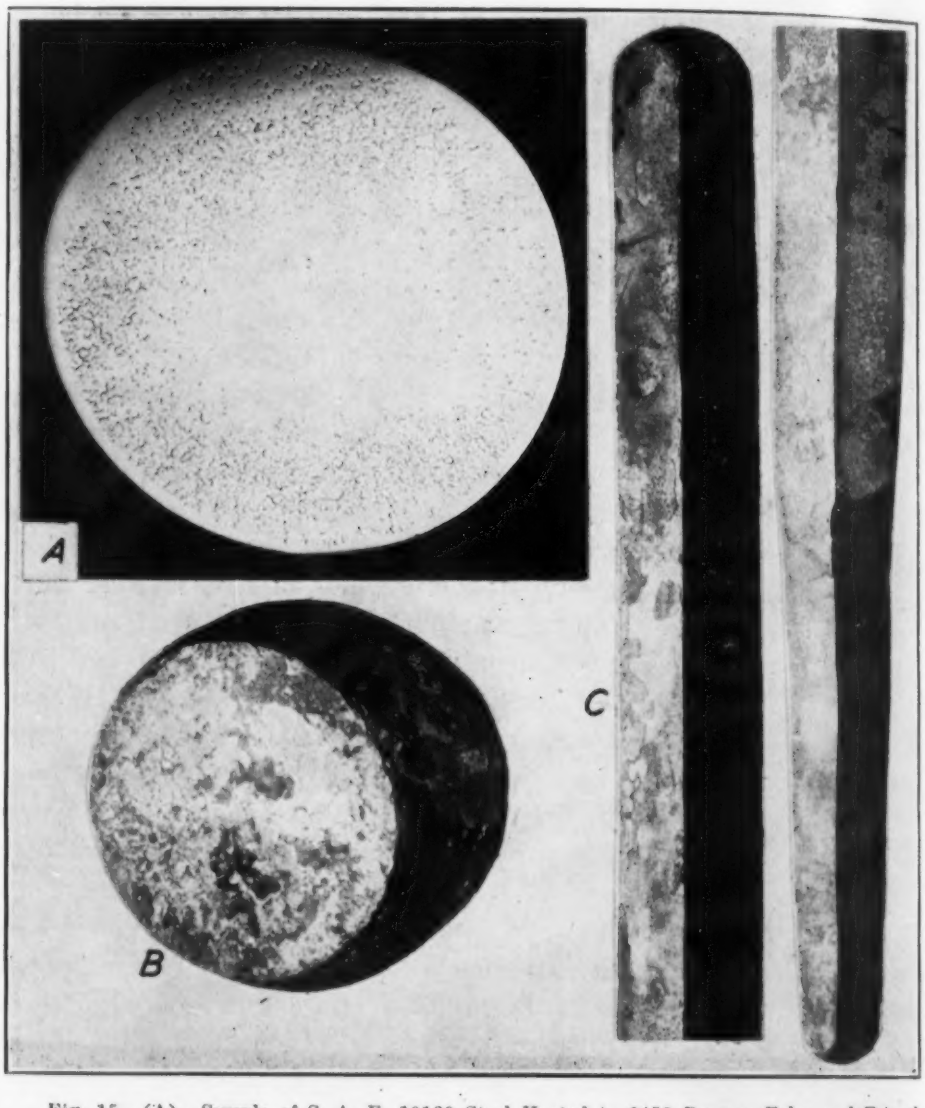

Fig. 15—(A) Sample of S. A. E. 10120 Steel Heated to 2450 Degrees Fahr. and Forged. The Steel is Burned Entirely on the Inside.
(B)—Sample of S. A. E. 10120 Steel which was Heated at the Same Time in the Same Furnace with Sample Shown at (A).
(C)—Sample of the ¾ Inch Bar Forged from this Sample at a Welding Heat.

polished and examined under the microscope. Longitudinal sections were cut from each end and transverse sections were cut at intervals of 4 inches along the bar.

These sections examined under the microscope gave no evidence of the presence of oxides, in fact the steel apparently had fewer small holes than exist in the original steel bar from which the sample was cut. Having been burned entirely on the inside, if burning

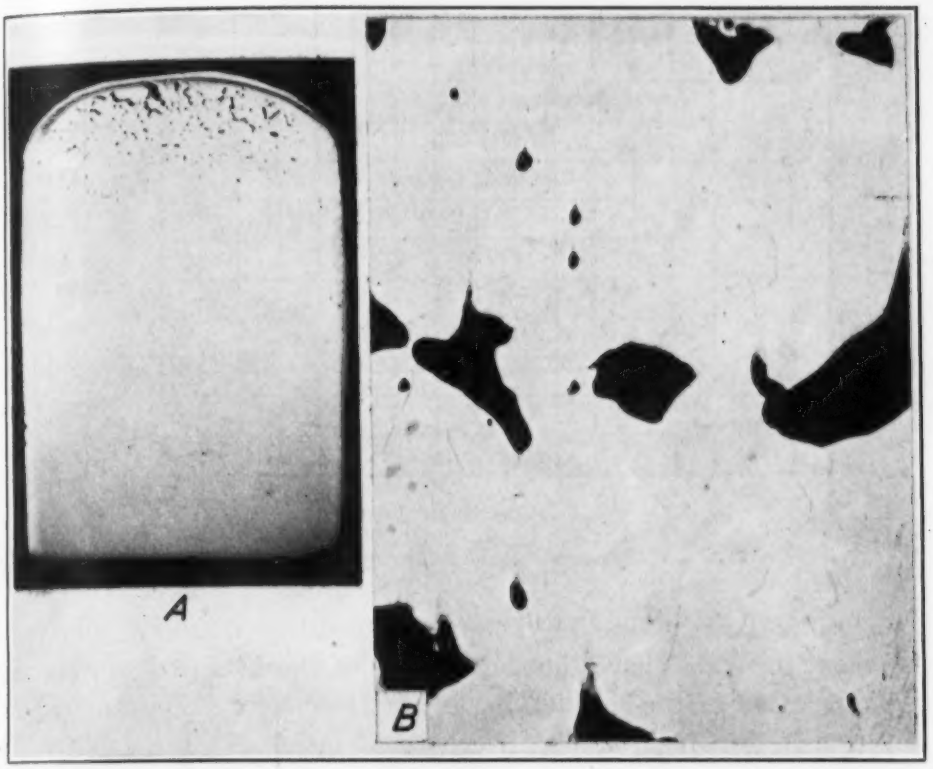

Fig. 16—(A) Location of Unwelded Voids in the Ends of the ¾ Inch Bar Forged from the Burned 10120 Steel. × 2.
(B)—Unetched Photomicrograph of Burned Section Shown at (A). × 100.

were necessarily accompanied by oxidation it would have been necessary for oxygen or other oxidizing gas to diffuse through the outside ring of good metal to cause burning on the inside. Since no oxides were found in the sections after forging, it is believed that here is additional proof that oxidation is not necessary to accompany what is called burning in the steel industry. Both of the samples that were cut off at the ends of the bar still showed the voids from burning near the end of the bar. Apparently a small area at each end of the bar did not receive enough mechanical working to weld the voids shut. See Figs. 16A and B.

It is evident that nearly all the voids welded up perfectly, leaving no trace of the previous burning except at the ends.

Relation of Burning Temperature to Solidus Line in Iron-Carbon Diagram

Both Stead and Stansfield state that the burned structure of

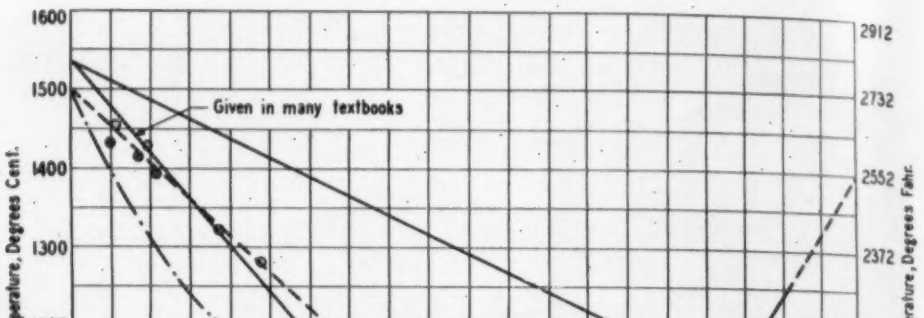

Fig. 17—Solidus and Liquidus Lines in Iron-Carbon Diagram.

a steel is largely due to the partial melting which results from heating the steel above the solidus line of the iron-carbon diagram. The position of the solidus line in the iron-carbon diagram is however open to considerable difference of opinion. The solidus line has been determined experimentally by three investigators, Carpenter and Keeling and Gutowsky, and the position of these lines differ widely.

Although commercial steels rather than iron-carbon alloys were studied in this investigation, the burning points in reducing atmospheres came quite close to the solidus line drawn by Carpenter and Keeling and do not check the solidus line on the Gutowsky diagram. Fig. 17 shows the solidus lines of Carpenter and Keeling, of Gutowsky and of that rather generally although not universally accepted in metallurgical texts. The burning temperatures, in reducing atmospheres, obtained in this study have been plotted on this composite diagram.

This investigation shows that the burning point of the alloy steels is but slightly lower than those for the plain carbon steels. No doubt the fact that these are commercial steels rather than pure iron-carbon alloys will cause the solidus points to be at variance with the theoretical position. However, it is felt that a careful research on pure iron-carbon alloys to determine more exactly the position of the solidus line would be profitable.

Conclusions

In conclusion it may be well to recall that the word burning is not an accurate word to use in discussing this phenomenon since it implies chemical reaction of steel with oxygen. This research has shown that this reaction is not necessary to produce the phenomenon that is generally called burning, but that burning is usually produced by a separation of the crystals leaving voids around the crystal boundaries causing a condition of brittleness or lack of strength or both.

The following table shows the temperature at which the various steels investigated will burn if forged immediately after heating in a direct-fired gas furnace when using a large excess of gas, and a large excess of air.

S.A.E. No.	Composition of Steel Per Cent Carbon	Per Cent Nickel	Per Cent Chromium	Atmosphere	Highest Temperature to which steel was heated without burning	Lowest Temperature to which steel was found to burn
1025	0.28	0.00	0.00	excess air	2545	2560
1025	0.28	0.00	0.00	turbulent " gas "	2625	2675
1045	0.47	0.00	0.00	excess air	2475	2500
1045	0.47	0.00	0.00	turbulent " gas "	2575	2625
1090	0.93	0.00	0.00	" air "	2400	2425
1090	0.93	0.00	0.00	" gas "	2400	2425
10120	1.19	0.00	0.00	" air "	2320	2350
10120	1.19	0.00	0.00	" gas "	2320	2350
2320	0.24	3.48	0.05	" air "	2570	2590
2320	0.24	3.48	0.05	" gas "	2600	2625
3140	0.43	1.20	0.39	" air "	2500	2525
3140	0.43	1.20	0.39	" gas "	2570	2590
3250	0.52	2.05	0.83	" air "	2500	2530
3250	0.52	2.05	0.83	" gas "	2525	2550

If the atmosphere in which the steel is heated is sufficiently oxidizing and turbulent, the steel becomes hotter than the furnace atmosphere by reason of the exothermic reaction between iron and oxygen. If this reaction proceeds fast enough, heat is generated faster than can be taken away by the surrounding atmosphere and thus the piece becomes hotter than the atmosphere. Due to this reaction the steels in the above table may burn in furnace atmospheres whose temperature is lower than that given for oxidizing conditions.

The greatest danger about burning is the fact that in many cases the steel may appear quite satisfactory on the surface while the center may be in very poor condition. There are no means of determining whether a specimen is burned except by sectioning the

piece. Hence it is apparent that there is no effective commercial method of inspection sufficiently reliable to detect all burned forgings.

It has been shown that a piece of steel which has been burned may be forged and that further by forging at a welding heat many of the voids may be welded up. However, even when there are no oxides it is not possible to be sure of welding all the voids shut. It is the author's opinion that many unexplained failures might be accounted for by the presence of voids due to burned steel which partially welded up by further working after burning so that only an occasional void was left.

Acknowledgements

For their help in carrying out the tests presented in this paper, the author is indebted to Messrs. W. Telfer, T. J. Kneebone, and J. H. Speirs for the forging of the steels, and to John A. Webber, who made many of the tests.

The author also wishes to express his appreciation to Professor A. H. White for his encouragement and suggestions in this study and to the American Gas Association, whose financial support made this study possible.

SALT BATHS FOR THE HARDENING OF HIGH SPEED STEEL

By Bengt Kjerrman

Abstract

This paper reports the results of a series of experiments on salt baths and salt bath containers used for heating high speed steel for hardening. Decarburization of the metal being heated is one of the difficulties encountered. The effect of the crucible material, salt used, and combinations of the two are reported. It is stated that a chamotte crucible as the container for barium chloride to which a sufficient amount of ferrosilicon was added, could be used with no risk of decarburizing high speed steel and with an increase in the life of crucible of about 4.5 times that obtained with molded silica crucible.

IT has long been known that high speed steel requires an unusually high hardening temperature as compared with ordinary tool steel, consequently there has been some difficulty in finding a suitable source of heat. High speed steel was originally heated for hardening in a blacksmith's forge. Later, open or closed furnaces and externally heated crucibles were used and even now this practice is met with rather frequently.

The heating of high speed steel in salt baths through which an electric current is passed is a very convenient method and is being used more and more. In this method, the electrodes are immersed in the salt bath and the heating is thus accomplished internally without overheating the refractory material of the container; which at the best has comparatively short life.

One of the difficulties often encountered in the use of the salt bath in the heating of high speed steel is that the steel may be decarburized in spite of the very short heating time, thus in order to reduce this decarburizing effect steels are preheated, in a muffle furnace before immersing in the high temperature salt bath. This preheating is also of importance in reducing the danger of heating cracks forming in the steel due to too rapid heating if immersed

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directly in the high temperature bath. It is the writer's experience however that such preheating is of minimum importance in reducing decarburization.

At S K F in Gothenburg investigations on different refractory materials for these salt bath furnaces have been carried out. The most important results obtained were that refractory material of chamotte[1] had a comparatively long life but gave an especially severe decarburization, and that refractory material of silica

Table I

Material	SiO_2 Per Cent	Al_2O_3 Per Cent	Fe_2O_3 Per Cent	CaO Per Cent	MgO Per Cent	Melting Point °C.	Squatting Temperature °C. at Loads of 1 kg/cm²
Chamotte	77.0	20.0	1.3	0.4	0.3	1690–1710	1350
Silica	96.4	1.0	0.4	2.0	traces	1750–1770	1650–1670
Alumo	14.5	79.4	2.2	3.9	...	1790–1825	1610
Silicon carbide	85 per cent silicon carbide					above 2000	1550

showed a shorter life, however, from a decarburization standpoint it was considerably more advantageous. As a result of these investigations, silica crucibles were adopted in spite of the shorter life.

The original investigations were carried out during the years 1919 and 1920, however, during the year 1927 these tests were repeated and extended so that in addition to chamotte and silica crucibles, crucibles of alumo[2] and silicon carbide were tested. Molded crucibles were used instead of crucibles built up from bricks as in the former tests, due to the fact that the silica bricks proved to be very brittle in handling. With the introduction of molded crucibles, the life of the container was increased to a maximum of 90 hours effective hardening time at an intermittent service of about 8 hours per day. The furnace was allowed to cool down at night and was turned on again in the morning.

The tests made in 1927 confirmed those previously made, as well as the previous experience, that the best material for use as crucibles was silica. The chamotte material gave severe decarburization as did also the alumo material. The alumo proved, however, to be the most durable but was too expensive. The silicon carbide crucibles were not suitable on account of their high electrical conductivity already at room temperature and also showed very short life in service.

[1] See Table I.

[2] See Table I.

When it seemed impossible to get better results with the methods then in use for investigating the different crucible materials, the interest was then turned to the study of suitable salt baths, which had up to this time been barium chloride and the slag forming on the bottom of the crucible. Salt which had been used for about 30 hours was analyzed, specimens were taken from the silica crucible and from the alumo crucible. The salt from the silica crucible contained about 1½ per cent of elements insoluble in water, consisting of oxides of barium, iron, silicon and aluminum.

The approximate composition, melting point and squatting temperature of the tested crucibles are shown in Table I.

The salt from the alumo crucible contained about 3.2 per cent of similar oxides which is somewhat more than twice as much as was obtained from the silica crucible. The slag taken from each of the crucibles at the same occasion was analyzed with the following results:

	Fe_2O_3 Per cent	BaO Per cent	SiO_2 Per cent	Al_2O_3 Per cent
Slag from the silica crucible...	23.5	45.5	30.2	..
Slag from the alumo crucible ..	91.8	3.5	1.3	3.4

These analyses from the salts and slags show that the salt in the silica crucible contains considerably less oxides than that in the alumo crucible and that the slag formed in the silica crucible contains considerably more barium oxide than that from the alumo crucible. Knowing that decarburization will take place in the alumo crucible but not in the silica crucible, it seems likely that the barium oxide is the main cause of decarburization, and that the salt through the decomposition of the silica crucible will be continuously purified from this barium oxide which is then absorbed by the slag.

In order to verify this, tests were made in an iron crucible with barium chloride. For the hardening tests, crucible-made high speed steel was used, the quenching temperature being 2325 degrees Fahr. (1275 degrees Cent.) Hardening tests were carried out with newly melted barium chloride; with newly melted barium chloride, mixed with 1.5 per cent Fe_3O_4; with newly melted barium chloride mixed with 1 per cent barium oxide; with newly melted barium chloride mixed with 2 per cent barium oxide.

No decarburization of the steel occurred with any of these baths excepting the one containing 2 per cent barium oxide. To the salt

containing 2 per cent barium oxide was added 1 per cent SiO_2 and a new hardening test was carried out. No decarburization of the steel was observed. To the same salt bath 1 per cent Fe_3O_4 was then added and a new hardening test was made, with a similar result.

Hence it is seen that Fe_3O_4 and SiO_2 do not decarburize high speed steel in heating, but with a sufficiently high percentage of barium oxide, decarburization will take place. Finally it is observed that a suitable addition of SiO_2 can eliminate the detrimental influence of barium oxide.

Practical tests were then carried out with a common silica crucible with the addition of SiO_2 in the form of sand. A liquid slag formed upon the surface of the bath which adhered to the steel to be hardened and was obstructive. Therefore, further work along this line was abandoned. Instead, tests were made in an iron crucible with the addition of ferrosilicon of the same quality as used by the steel mills, having a silicon content of 45 per cent. Pure barium chloride was fused with 3 per cent barium oxide and a hardening test was made. The quenched high speed steel showed a decarburization of 0.08 millimeters after heating only 2 minutes in the bath. This bath proved to be a very severely decarburizing one.

Then 1 per cent ferrosilicon was added. At this addition a very violent reaction took place in the bath. Following the same heating time and subsequent quenching the steel showed a decarburization of 0.06 millimeters. This showed an improvement over the first bath. To the bath was further added 1 per cent ferrosilicon and the hardening tests were repeated. No decarburization was observed after this test. Another 1 per cent ferrosilicon was added with similar results. This test showed that the decarburization was more likely to be due to the inability of the crucible to regenerate the salt, say automatically, than to the fact that the crucible itself reacts with the salt forming compounds which have a decarburizing effect.

Upon the addition of ferrosilicon to an acid crucible it would be assumed that it would not be necessary to regenerate the salt. Practical tests were therefore made with a silica crucible to which different amounts of ferrosilicon had been added, and after some preliminary tests the following additions were used: 10½ ounces in the morning and 7 ounces every hour. The alloy was added in

the form of powder and by a scoop which gave a calculated quantity by weight. No appreciable increase in the endurance of the crucible resulted from this addition, but an obvious advantage was obtained by the easy removal of the formed slag. Usually by the use of a silica crucible there will form on the bottom of the crucible a liquid, tough slag which cannot be removed from the salt by means of a scoop. After one week's run this slag has risen so considerably in the crucible that it impairs the hardening of longer pieces, sticking to these and being colder than the salt. Through the addition of ferrosilicon the crucible could be used continuously to its full depth.

Since the addition of ferrosilicon has little effect in increasing the life of the silica crucible, tests were made with a chamotte crucible with the same corresponding percentages as used in the tests with the silica crucible. With 3 per cent ferrosilicon no decarburization in the hardened steel was observed but the life of the crucible was more than 75 per cent greater than the corresponding silica crucible. Instead of the maximum effective running time of 90 hours for the silica crucible, the chamotte crucible stood up for 160 hours. The slag was easily removed although it was tougher in the chamotte crucible than in the silica crucible. With the chamotte crucible it was proven that the ferrosilicon addition of 3½ ounces in the morning and in the evening and 3½ ounces per hour was quite sufficient to guard against decarburization and to give a slag which was easily removed.

As the slag during the useful life of the crucible could be removed continuously, an improvement could also be made by heating the furnace during the night. Such tests had earlier been carried out with silica crucibles where no ferrosilicon had been added to the salt. It was found that after the first time the crucible had been heated it could easily be kept warm during the night with a very moderate current, but when the slag began to rise a considerably stronger current was required notwithstanding it occurred very often that the current was interrupted and the furnace went out. On the basis of keeping the furnace at 1830 degrees Fahr. (1000 degrees Cent.) during the night, an increase of effective hardening time of 1½ hours per day more was obtained. During the night the crucible was covered with a free asbestos plate upon which a suitable lid with edges was placed—this forming an insulating air layer between the asbestos plate and the lid.

As a result of this investigation it has been established that it is possible, without any risk of decarburizing the high speed steel, to use chamotte crucibles or furnaces bricked of chamotte for heating high speed steel to its hardening temperature in barium chlorides, if to the barium chloride is added a sufficient amount of ferrosilicon. With this addition the possibility of entirely removing the inconvenient slag formed on the bottom of the crucible is also achieved.

A chamotte crucible being about 25 per cent cheaper than a silica crucible and besides lasting at least for a 75 per cent longer time, considerable savings are made in respect to purchase and bricking costs as well as interruptions in service.

In order to fully make use of the chamotte crucible it is also required that the electrodes be of suitable and sufficiently heavy material. With a crucible having a section of 9 x 9 inches we find that it is necessary to have 4 electrodes and these should be made of the mildest steel, having a width of 5 inches and a thickness of 2 inches. Preferably they should also be entirely immersed in the salt and countersunk in the walls.

A first test with a furnace so designed, with cut bricks, showed a total life of 968 hours, the effective hardening time being 276 hours; a second test gave the corresponding figures of 1034 and 320 hours respectively and a third test gave 1249 and 391.5 hours respectively. Although the bricks on the cut surfaces were severely attacked, the crucible was still in a usable condition, the interruption being caused by the electrodes which were consumed. The electrodes had broken in the bend where they came out from the bricks. The attack was rather uniform all over the electrode, the part around the bend, however, being somewhat more corroded.

A NEW FURNACE FOR HEAT TREATING HIGH SPEED STEEL

By Wesley B. Hall

Abstract

This paper describes a new electric salt bath furnace for heat treating high speed steel which is being intensively used in a number of plants. The novel feature is that the bath is heated by current flow through the bath itself, from an immersed electrode to the pot wall. This permits mounting the pot directly in a heat insulating support with no heating chamber around it. The heat is generated in the bath, and the temperature gradient is all downhill out through the pot and support. This results in longer life, lower cost, and higher permissible temperatures than with the usual resistance heaters for salt baths. A transformer is required for each pot to supply the low voltage and high current needed. The construction operation, electrical characteristics, and power consumptian of these furnaces is discussed.

A NEW type of electric salt bath furnace for hardening high speed steel has been developed, and tried in industry in production service for more than a year. This furnace uses a salt bath suitable for heating high speed steel to its hardening heat. The salt melts at about 1750 degrees Fahr. and may be used at any temperature above that up to 2500 or 2600 degrees Fahr. It is very stable, does not fume nor decompose, and is neutral to the work, neither carburizing nor decarburizing it. The advantages of such a salt bath for such high temperature work are obvious. The bath covers the work, excluding all contact with air, thus preventing scaling. A film of the molten salt adheres to the work upon removal, protecting it during transfer to the quenching operation. This same salt may be used in a preheat pot at about 1800 degrees Fahr., to give a gradual warming up of the steel to be treated. The salt will freeze about the cold work protecting it and bring it slowly up to temperature as the frozen layer melts off, the tem-

The author, Wesley B. Hall, Yale University, New Haven, Conn., a member of the society, is consulting engineer to the Bellis Heat Treating Company, Branford, Conn. Manuscript received April 19, 1929.

perature of the pot being only slightly above the melting point of the salt. Excellent results have been secured without separate preheating by putting cold work directly into the high temperature bath and letting this same frozen salt layer cushion the warming up process. The heating is in general more rapid and more uniform in such a bath than in an oven-type furnace.

But all these advantages were to some extent offset by the difficulty of holding and heating the bath. In fuel-fired furnaces previously used the bath was contained in pots usually of steel with a gas or oil flame outside of the pots. The pot life was short, daily replacement being not unusual. This was because of the rapid corrosion of the outside of the pot which was in contact with the flame. The heat loss was high, which meant a high fuel cost and hot uncomfortable surroundings. The combustion was noisy, and the disposal of the products of combustion was a problem.

The New Method of Heating

The usual type of electric heating, consisting of resistance heaters around the pot, with all of its obvious advantages could not be applied here because the operating temperature was above the melting point of the usual nickel-chromium resistors. This situation brought about the development of the electric furnace described. In this, the bath is contained in the same sort of pot, but the bath itself is heated by the passage of an electric current through it. This is accomplished by immersing an electrode in the bath and passing a current from it to the pot wall, or by immersing two electrodes in the bath and passing current between them. The resistance characteristics of the molten bath are such that a very large current is required at a low voltage—usually between ten and twenty volts. This voltage is supplied from a transformer whose secondary is permanently connected to the electrode and the pot. The pyrometer controller is placed in the primary circuit of this transformer.

A mathematical analysis of the resistance of such an arrangement of bath and immersed electrode shows that the resistance is not greatly affected by the distance of the electrode from the pot wall (it is a logarithmic function,—halving the distance decreases the resistance 20%) but is inversely proportional to the electrode immersion. Hence the electrode is mounted in a clamp which

Fig. 1—Photograph Showing a Typical High Speed Steel Hardening Unit Consisting of Three Pots Mounted in a Heat Insulating Support. The Pots are Operated at 1800, 2300 and 1100 Degrees Fahr.

permits it to be raised or lowered in order to change the amount of power used.

Description of Furnace

A typical high speed steel hardening unit consists of three pots, mounted in a heat insulating support, containing the preheat, high temperature, and quench bath (Fig. 1). The pots are 10 by 14 inches, 8 by 14 inches and 12 by 14 inches, and are operated at 1800 degrees Fahr., 2300 degrees Fahr. and 1100 degrees Fahr. The preheat and high temperature pots both contain the high temperature salt bath. The quench pot contains a low temperature salt which melts at about 1000 degrees Fahr. Because they operate below the melting point of nickel-chromium resistor alloys, the preheat and quench pots might be electrically heated in the conventional manner, with resistance units built into a heating chamber around the pot, in the supporting structure. However, experience has shown decided economy in cost of operating as well

as initial cost from heating all three pots in the same manner by direct conduction through the salt. Therefore three transformers are provided, one for each pot, with three pyrometer controllers operating in the primary circuits of the transformers (Fig. 2). The transformers have primary taps to give ratios of 220 to 10, 12, 14, or 16 volts, but are of different current capacities. The secon-

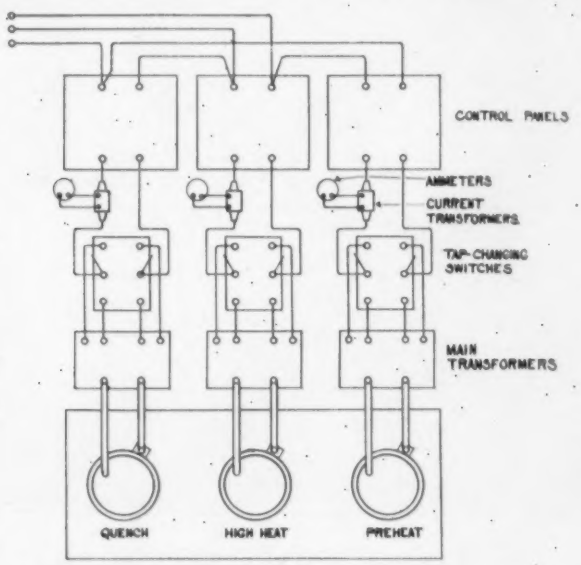

Fig. 2—Diagram Showing the Electrical Connections for the Heat Treating Unit Shown in Fig. 1.

daries are connected to the pots and the electrodes with copper bus bars of 3 square inches cross section. These connections must be made with as few joints as possible, and all joints must be very carefully made, as the current is so high that a little resistance will cause excessive heating. The electrode is made of 1¾ inch round copper to within about 18 inches of the bath, where it changes to 1¾ inch round iron or other heat resisting material; this part being immersed in the bath about 12 inches.

The preheat pot takes about 1700 amperes at 12 volts, drawing 95 amperes from the 220 volt line. The high temperature pot takes about 2100 amperes at 12 volts, drawing 115 amperes from the line. The quench pot takes 100 amperes at 10 volts, drawing 45 amperes from the line.

Power Consumption

The power consumed is used in supplying the heat losses of

the pots and in heating the work from room temperature. The heat losses are smaller than with any other type of pot furnace, since the heat insulation begins right at the pot wall and there is no combustion chamber around the pot. Also the temperature gradient is downhill all the way from the bath out through the pot wall and the support. There is no region of supernormal temperature outside the pot required to force heat into the bath. The heat is generated right in the bath itself. This means that the losses through the bottom and sides of the support can be made a fraction of a kilowatt, and are quite negligible. The large loss occurs as radiation from the surface of the bath and the top rim of the pot. This loss is about 7, 15 and 3 kilowatts respectively for the three pots, uncovered. When working at the rate of 100 pounds of steel per hour, the steel requires 11 kilowatts to heat it to 2300 degrees Fahr. This power is supplied partly from the preheat pot and partly from the high temperature pot. However, the steel carries enough heat into the quench pot to supply that pot's losses, so the consumption during operation is about 7 plus 15 plus 11 = 33 kilowatts. To this must be added about 10 per cent for losses in the bus bars and transformers, making the total average input about 36 kilowatts or 0.36 kilowatt hours per pound of steel.

It is preferable to hold the baths molten over-night, each at a temperature just above its melting point. The power required for this will depend upon the effectiveness of the covers used. With the ordinary shop covers the average holding consumption is about 8 kilowatts, but improved covers substantially reduce this.

Starting

To heat from the holding temperature to operating temperature requires about 1½ hours. To start from cold requires 4 or 5 hours. The high temperature salt is a poor conductor when frozen, and while it will conduct enough to start by conduction if the voltage is raised to about 30 volts, yet the process can be considerably accelerated by directing a portable gas or oil torch into the pot. The quench bath is a complete insulator when frozen and must be started by initially melting a puddle with a torch or with an arc between carbon electrodes temporarily attached to the same transformer that supplies the furnace. Once the puddle is started, the melting is rapid.

Life

In continuous production, for 8 hours a day, holding molten over night, the electrodes last from two to three weeks and the pots last one to two weeks (6 to 12 heats), for the high temperature pot —the variation being due to varying practices, production, temperatures and operators. The electrodes and pots for the preheat and quench last periods of several months. Electrodes can be changed in a few minutes with no loss of production. Each pot is placed inside a steel container which retains the bath when the pot fails and from which the bath may be ladled into the new pot if done promptly, or chipped out if allowed to freeze. Work is now being carried on to develop materials for the electrode and pot which will give longer life, although the present life is quite satisfactory and in keeping with present day high temperature practice.

Conclusion

These furnaces are being used in a number of different industries, handling up to 150 pounds of steel an hour in continuous production. While there will undoubtedly be continued development and improvement, yet they have shown themselves practical and economical in operation and it is believed that they offer a real advance in the art of heat treating high speed steel.

EFFECT OF ANNEALING ON THE GRAIN STRUCTURE OF EXTREMELY HARD-ROLLED STEEL RIBBON

By N. P. Goss

Abstract

The author has pointed out that when a hard-rolled steel ribbon of low carbon content was annealed between 1200 degrees Fahr. and just below the upper critical temperature a new orientation of grains developed whereas when such annealing was carried out at a temperature below 1200 degrees Fahr. no change in orientation resulted but instead large grains grew which apparently had random orientation. The new orientation as in the first case is accounted for through the formation of twinned crystals in which the (2 1 1) planes are the twinning planes.

THE purpose of this investigation is to show what occurs when a hard-rolled steel ribbon is annealed at various temperatures. When a steel ribbon is cold-worked, the grain structure of the annealed specimen is fragmented and these grain fragments are oriented in a definite direction with respect to the direction of cold working. In the case of alpha iron (space lattice is of the body-centered cubic type) the grain fragments tend to set the (1 1 0) planes along the rolling direction and the (1 0 0) planes tend to lie in the rolling plane as shown in Fig. 1.

The steel used in this experiment contained 0.06 per cent carbon and about 0.35 per cent manganese. It was cold-rolled down to a ribbon 0.002 inches thick, the area reduction being about 95 per cent. Fig. 2 is the X-ray spectrogram of the cold-rolled structure. The X-ray beam was transmitted at right angles to the surface of the ribbon (rolling plane).

The X-ray pattern shows what was stated above, that in a cold-rolled steel ribbon the (1 1 0) planes tend to lie in the direction of rolling and the (1 0 0) planes in the rolling plane. It also tells us that the grains are completely fragmented and the lattice parameter has not been changed by the drastic plastic deformation of the annealed grain structure. The deformation of the grains takes

The author, N. P. Goss, a member of the society, is a physicist, American Steel and Wire Company, Cleveland. Manuscript received April 9, 1929.

place by slip and rotation along the (1 1 0) planes because these planes have the greatest spacing and atomic concentration, and therefore should offer least resistance to forces of deformation.

The effect of annealing on the cold-worked structure at various temperatures will be shown in the X-ray spectrograms which follow. The annealing was done in a lead bath because the temperature of such a bath is very easily controlled. The steel ribbon was cut into short lengths and these were annealed at the following temperatures for about 2 minutes: 950, 1000, 1100, 1200, 1300, and

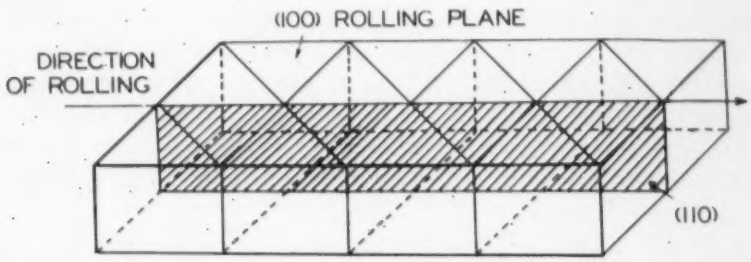

Fig. 1—Diagram of X-ray Spectrogram of Cold-Worked Alpha Iron Wherein the Grain Fragments Tend to Set the (1 1 0) Planes Along the Rolling Direction and the (1 0 0) Planes Tend to Lie in the Rolling Plane.

1600 degrees Fahr. Annealing at these temperatures caused grain growth and in most cases the cold-worked structure was completely recrystallized. Also this short time of annealing prevented excessive oxidation of the specimens.

Fig. 3 is the X-ray spectrogram of a specimen annealed at 950 degrees Fahr. It shows that recrystallization of the cold-worked structure did not occur. No doubt a longer time of annealing would cause grain growth. Comparing Figs. 2 and 3 it will be seen that they are the same.

Annealing at 1000 degrees Fahr. for 15 minutes caused grain growth but it is not marked. Fig. 4 is the X-ray pattern obtained but the reproduction of the negative does not show these new grains distinctly because they are rather small and diffuse. However, when a specimen was annealed at 1100 degrees Fahr. extremely large grains were produced and Fig. 5 shows the X-ray pattern for this sample. The pattern is very interesting because it shows that all the crystalline debris due to cold work did not begin to recrystallize and it retained the orientation produced by cold rolling.

Fig. 6 is the X-ray pattern of a specimen annealed at 1200 degrees Fahr. It will be seen that the crystalline debris is completely

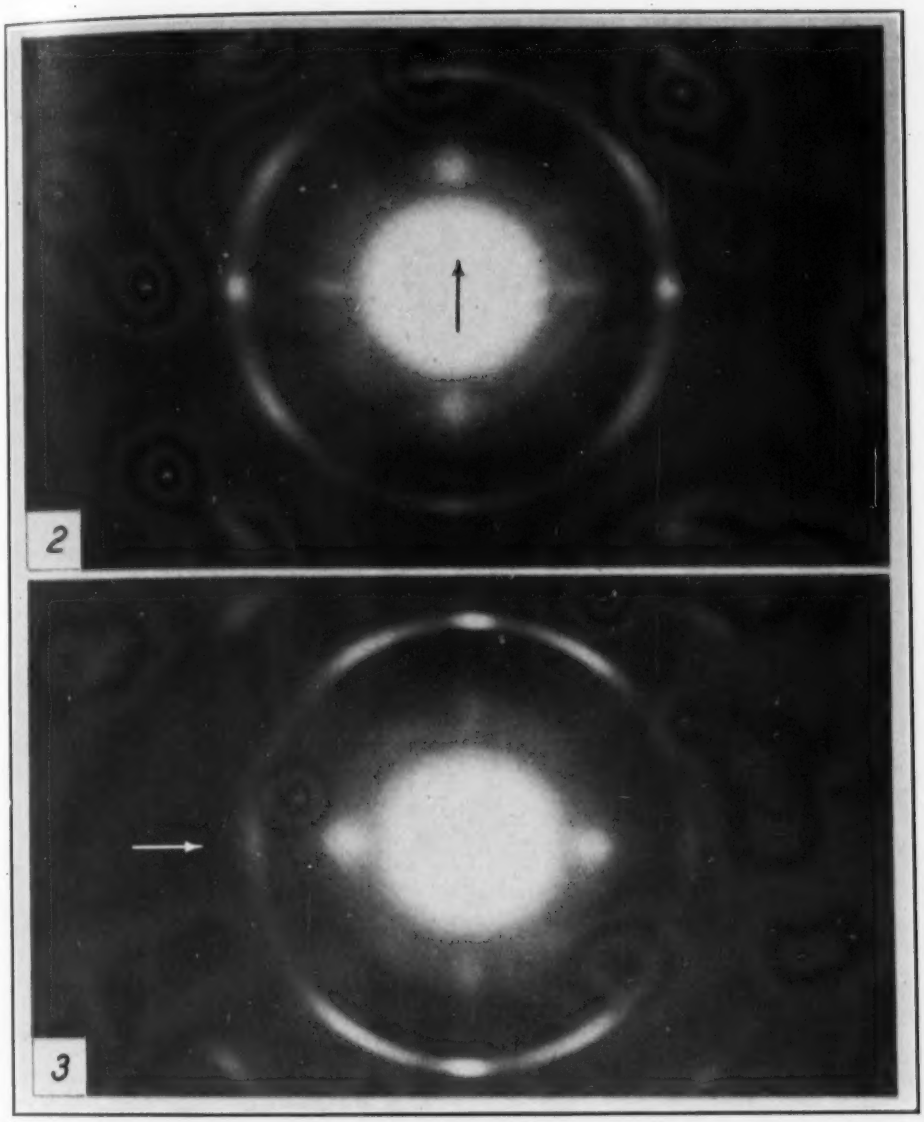

Fig. 2—Spectrograms of Hard-rolled Steel Ribbon, Area Reduction 95 Per Cent. Arrow Indicates Direction of Rolling. X-ray Beam Was Made Monochromatic by a Zirconia Filter 0.015 Inches Thick. The X-ray Beam Was Transmitted at Right Angles to the Surface of the Specimen. Fig. 3—Spectrogram of Hard-Rolled Ribbon Annealed at 950 Degrees Fahr. for 2 Minutes.

recrystallized and the new grains have assumed an orientation entirely different from that of the cold-worked structure. In Fig. 2 there are only four distinct diffraction spots due to the (1 0 0) planes. In Fig. 6 there are eight such spots due to the (1 0 0) planes. This number of diffraction spots can be accounted for if we assume the normal to the (2 1 1) plane to lie in the plane which is normal to the rolling plane in the direction of rolling.

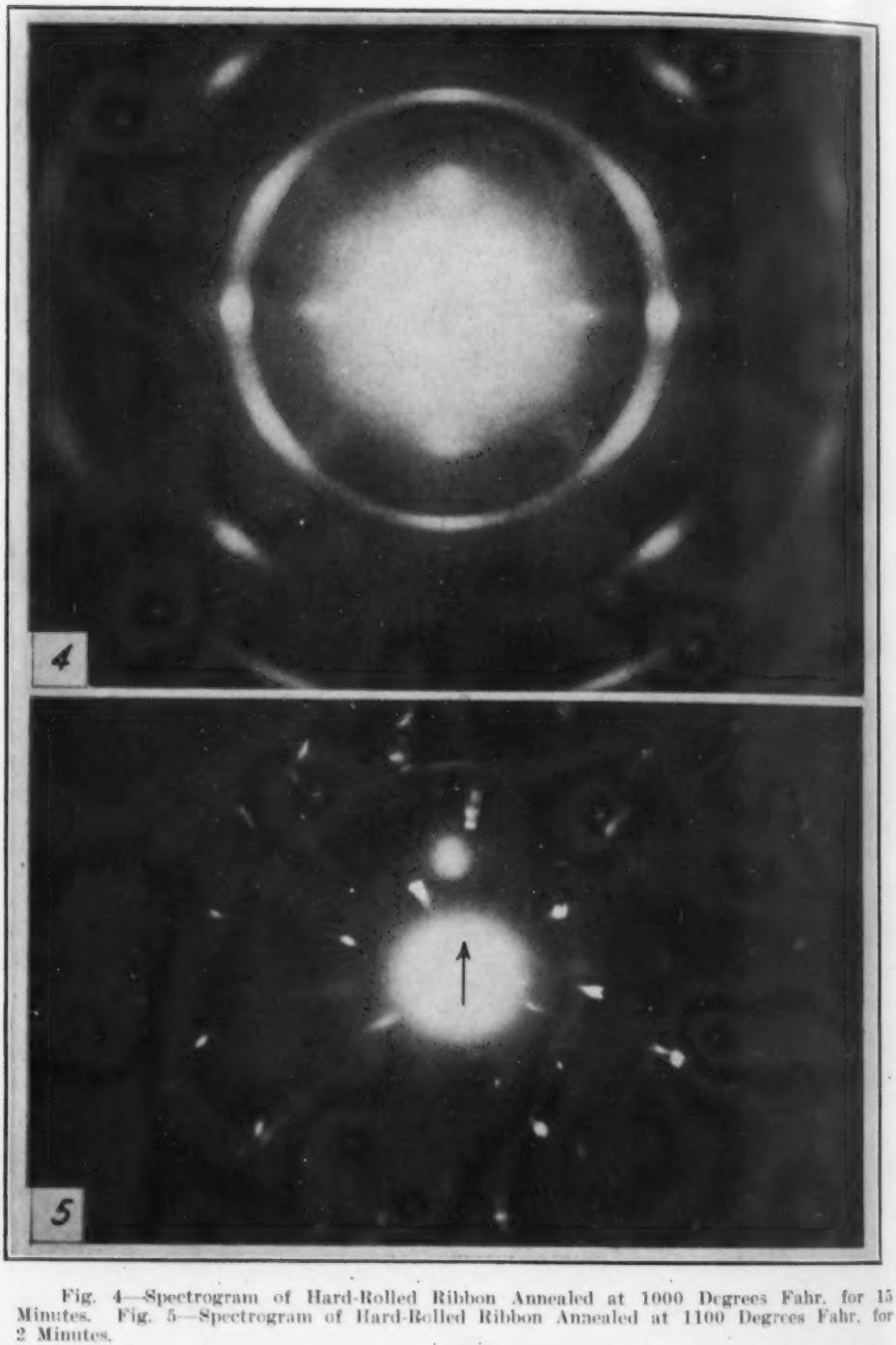

Fig. 4—Spectrogram of Hard-Rolled Ribbon Annealed at 1000 Degrees Fahr. for 15 Minutes. Fig. 5—Spectrogram of Hard-Rolled Ribbon Annealed at 1100 Degrees Fahr. for 2 Minutes.

In previous experiments on hard-drawn round wires with area reductions up to 98 per cent, it was found that the recrystallized

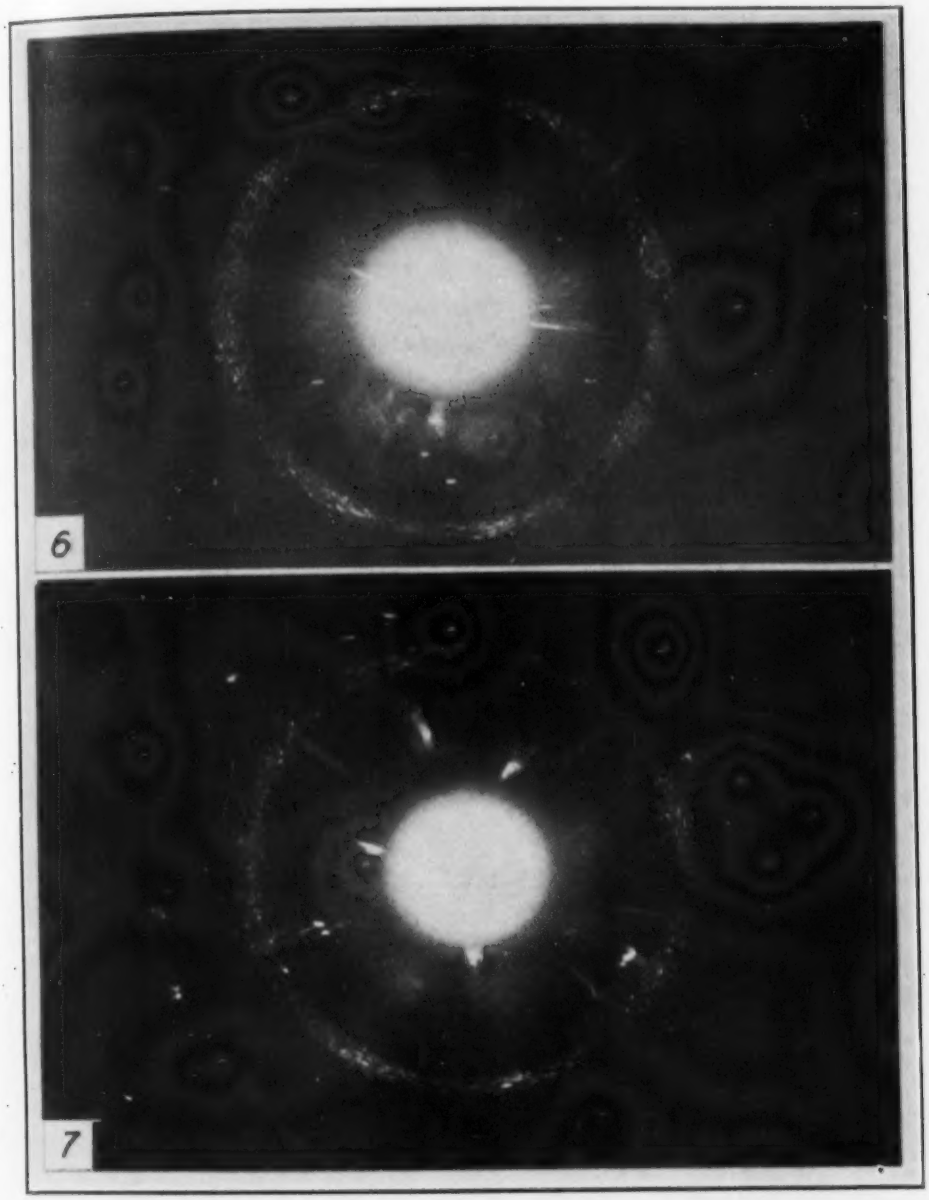

Fig. 6—Spectrogram of Hard-Rolled Ribbon Annealed at 1200 Degrees Fahr. for 2 Minutes. Fig. 7—Spectrogram of Hard-Rolled Ribbon Annealed at 1300 Degrees Fahr. for 2 Minutes.

grains retained the orientation of the cold-worked structure, i. e., the recrystallized grains tended to have the (1 1 0) planes lie along the axis of the wire. This change in orientation presents an entirely different problem and it is rather difficult to state the reason for this peculiar change in orientation. It will also be seen that

the crystalline debris has completely recrystallized at this temperature and the grains are nearly perfect in structure. A few large grains are also present; perhaps they started to grow a little sooner than the smaller grains.

Fig. 7 is the X-ray spectrogram obtained when a specimen is annealed at 1300 degrees Fahr. It will be seen that it is similar to Fig. 6. The small grains are about the same size and are nearly perfect in structure. As in Fig. 6, there are also a few large diffraction spots due to grains which are fairly large. The new orientation found in the sample annealed at 1200 degrees Fahr. is also present in this one.

Another specimen was annealed at 1600 degrees Fahr. in order to determine whether or not this new orientation persists at a temperature just below the upper critical temperature. Fig. 8 shows that it is retained even at 1600 degrees Fahr. The grains are all perfect in structure and nearly uniform in size. No large grains are present, perhaps due to the fact that the temperature gradient was so rapid around 1100 degrees Fahr. that large grains did not get a chance to grow.

When this steel ribbon was annealed at a temperature above the upper critical temperature, it was found that the new orientation developed between 1200 degrees Fahr. and below the upper critical temperature was entirely removed, a grain structure of random orientation being developed. Its X-ray spectrogram is shown in Fig. 9. The grains are rather small and imperfect in structure.

Geometrical Intérpretation of the Orientation Developed in an Annealed Hard-Rolled Steel Ribbon

From Fig. 8 it is possible to determine the orientation of the various planes with respect to the direction of rolling. The arrow indicates the rolling direction. Fig. 10 is a reproduction of Fig. 8 and shows the regions of maximum intensity. In order to have the intensity maxima marked (1) and (2), it is necessary to have a set of (2 1 1) planes oriented so that the normals to these planes lie in the direction of rolling. This means that another set of (2 1 1) planes will tend to lie in the direction of rolling and these planes must reflect to the positions (3) and (4). Upon examining Fig. 8, it will be seen that such reflections from the (2 1 1) planes are present and are maximum at the points (3) and (4) as indicated in

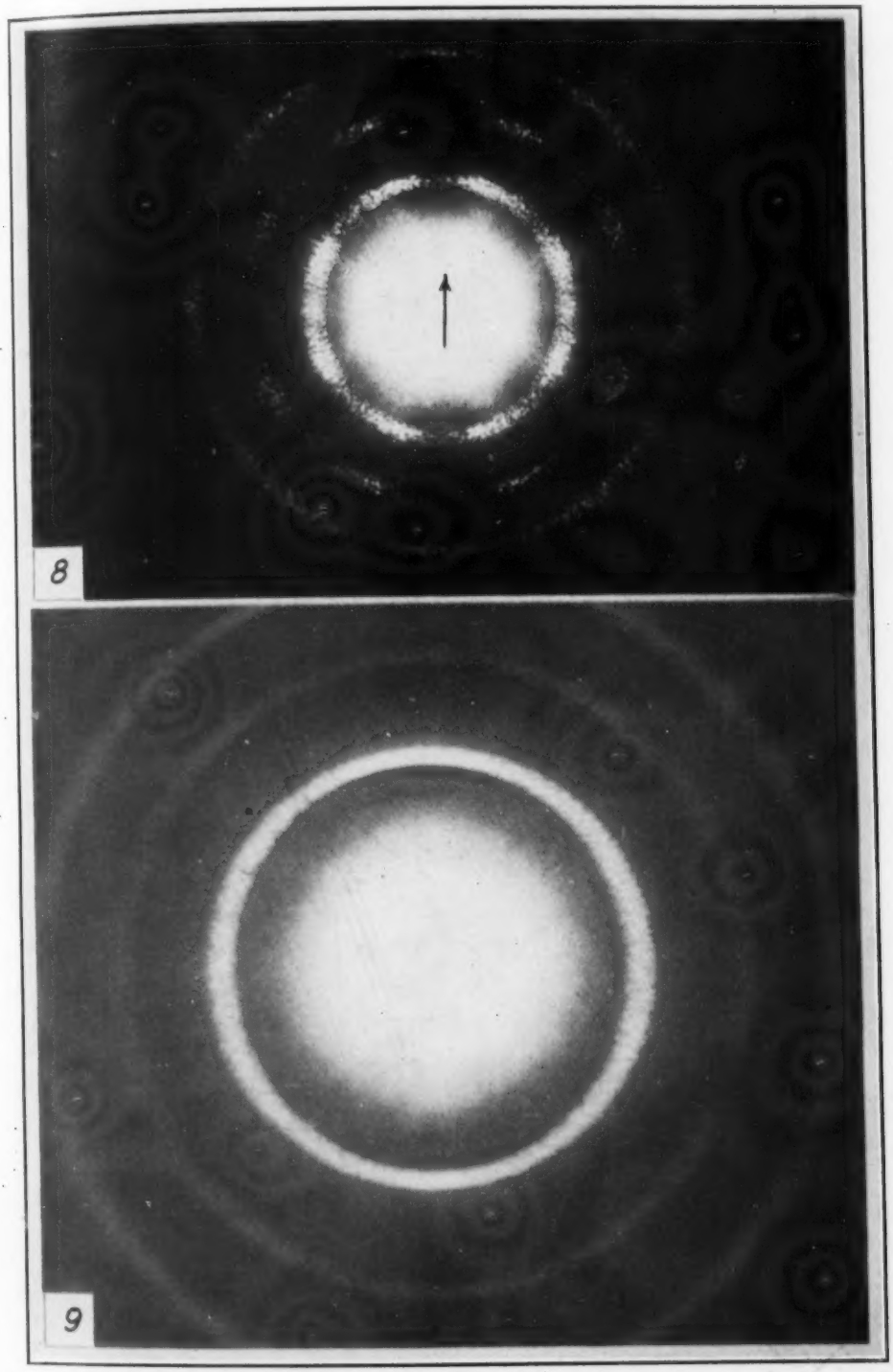

Fig. 8—Spectrogram of Hard-Rolled Ribbon Annealed at 1600 Degrees Fahr. for 2 Minutes and Cooled Slowly. Fig. 9—Spectrogram of Hard-Rolled Ribbon Annealed Above the Upper Critical Temperature for 2 Minutes and Cooled Rapidly in Air.

Fig. 10. This means that one set of (2 1 1) planes tend to lie in the rolling plane or in the surface of the steel ribbon, while another set of (2 1 1) planes which are at right angles to the first set tend to lie in the direction of rolling.

Upon examining Fig. 8, it will be seen that there are eight diffraction maxima shown on the film due to reflections from the (1 0 0) planes, while in Fig. 2 there are only four such diffraction

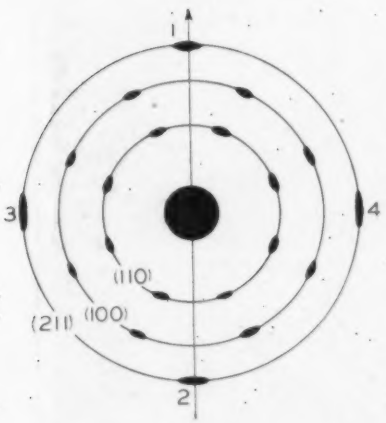

Fig. 10—Reproduction of Fig. 8 Showing the Regions of Maximum Intensity. The Arrow Shows the Direction of Rolling.

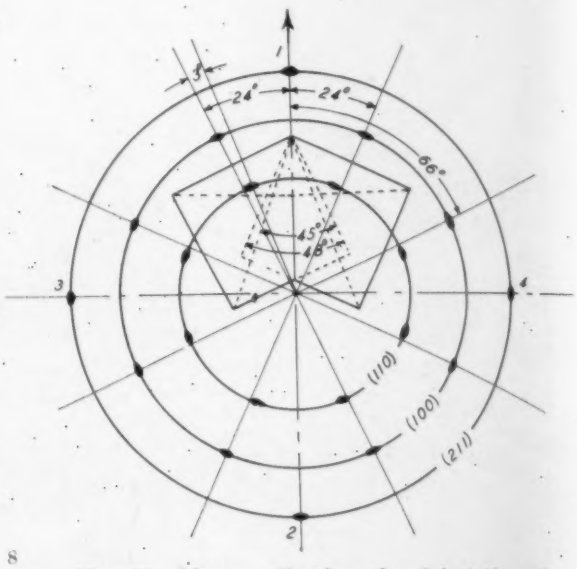

Fig. 11—Diagram Showing the Orientation of Twinned Crystals in Respect to the Direction of Rolling. Direction of Rolling is Indicated by Arrow.

maxima. These are easily accounted for if we assume that the crystals are twinned and that the twinning planes are of the 2 1 1 family.

The angle between the direction of rolling and the first diffraction maxima due to the (1 0 0) planes is about 25 degrees. The angle between the (1 0 0) and (2 1 1) plane is 65 degrees 54 minutes or about 66 degrees and the compliment of the angle is 24 degrees, which checks within 1 degree of the angle measured on the film. It will also be noted that on Fig. 8 the diffraction maxima due to the (1 1 0) planes and those due to the (1 0 0) planes almost lie on lines joining the central image. By measurement it was found that the angle between the corresponding diffraction maxima, (1 0 0) and (1 1 0) which lie nearly on the same line, was about 3½ degrees while by calculation it was found to be 3 degrees.

Fig. 11 shows the orientation of these twins with respect to the

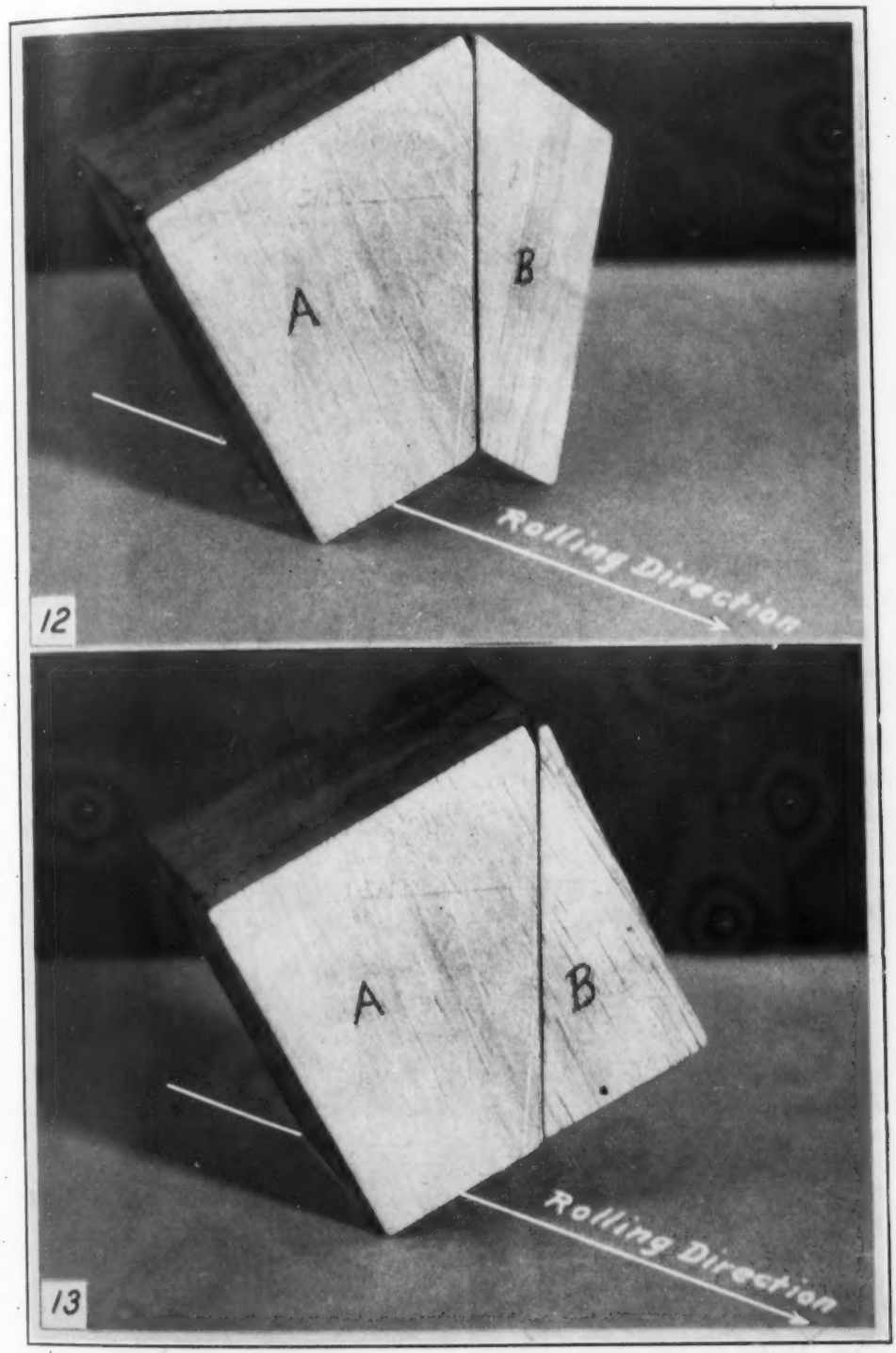

Fig. 12—Photograph of a Model of a Cube Showing Manner in Which the Twin Crystal is Formed by Rotating Part A About Part B 180 Degrees Through the (2 1 1) Plane. Fig. 13—Photograph of the Same Model as in Fig. 12 Showing the Original Cubic Formation by Rotating the Twinned Cube Through 180 Degrees.

direction of rolling. The (2 1 1) twinning planes tend to lie in the direction of rolling. Fig. 12 is a model of such a twin and shows how it is oriented with respect to the direction of rolling.

If the (A) portion of the twin is rotated 180 degrees about the (B) portion, a cube is again obtained as shown in Fig. 13. Upon examining the twin it will be seen that the (A) portion is a mirror image of the B portion which is a condition that must be fulfilled because a twin always possesses a higher degree of symmetry than its usual crystal form, a body-centered cube in this case.

Summary

1. When a hard-rolled steel ribbon of low carbon content was annealed between 1200 degrees Fahr. and just below the upper critical temperature a new orientation was developed.

2. Annealing below 1200 degrees Fahr. did not produce this new orientation, only large grains grew which appear to have a random orientation.

3. This new orientation is accounted for if it is assumed that twinned crystals are produced in which the (2 1 1) planes are the twinning planes. These twins are oriented in such a manner as to have the (2 1 1) twinning planes lie in the direction of rolling as shown in Fig. 12.

PROPOSED CONTROL METHODS FOR SMALL HEAT TREATMENT PLANTS

By Welton J. Crook

Abstract

A hardness testing instrument and the use of a furnace are shown by the author to be adequate equipment with which a small heat treatment plant may obtain considerable information about its raw materials and products. By the use of hardness figures obtained and the use of formulas it is possible to obtain a close estimate of the tensile strength of steel, and an estimate of the fatigue strength which will be close enough for engineering purposes. Regeneration tests and macro-etching are discussed in relation to the inspection of raw materials for ability to give results after heat treatment.

Introduction

DURING the last few years, a large number of small plants have been established in this vicinity, in which more or less heat treating of steel is undertaken in connection with manufacturing. Modern competition has made it necessary for many of these plants to turn out high class work, but their scale of operations may not justify the employment of a technologist or the equipment of a metallurgical laboratory to inspect their steel purchases or control their treating processes. It is just as important that a small plant should have some control as it is for a large one. Very often questions arise regarding quality of raw materials, strength of steel, and even fatigue strength.

In this paper are presented a few suggestions by means of which, with inexpensive and simple apparatus, a non-technical man may answer a number of questions which may arise concerning steel.

Relation of Hardness to Other Physical Properties

No brief is held for any particular type of testing machine, but

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for the purpose of a small plant, it is believed that the Rockwell hardness tester offers more advantages for general purposes than any other. With the use of this machine, or a Brinell machine, a great deal of useful information may be obtained regarding steel. It can be shown that a relation exists between hardness, tensile strength, and fatigue strength. In combination with certain furnace tests, hardness can also be used as a basis of judgment of the quality of steel for heat treating purposes.

Everyone who has to do with the treating of steel is familiar with the S.A.E. tables, and has noted that these tables give both the scleroscope and Brinell hardness corresponding to the physical properties of steel which has been quenched and tempered at various temperatures.

The methods used for the commercial determination of hardness of steel are more simply carried out than those used for the determination of other physical properties. If a reliable ratio can be determined between hardness and tensile strength, it would be useful as a quick method of obtaining approximate values where more elaborate and exact tests were unavailable in a small shop.

The determination of ultimate strength of steel is not a difficult operation, but it does require the use of expensive apparatus, and in most cases the preparation by machining of suitable specimens. In every case, the specimen tested must be destroyed in making the test. In many cases, the finished article is of such shape that a suitable tensile specimen cannot be produced.

It has long been known that a close agreement exists between Brinell hardness and ultimate strength. The S.A.E. diagrams for heat treated steels, both plain and alloy, record Brinell and scleroscope hardness as well as the other physical properties, but they do not record the hardness or other properties of steels in the untreated condition. The S.A.E. tables are, however, limited only to steels with a restricted range of carbon content.

Dillner's Formula

Besides the S.A.E. tables, a number of formulae have been suggested for converting Brinell hardness to ultimate strength, but after investigating several of these, the formula of Dillner was selected as giving the most satisfactory results.

Tensile Strength-Hardness Factors
Dillner's Formula

Tensile Strength (1000 pounds per sq. in.) = C × Brinell Number

Brinell Hardness Number	Value of C	
	Ball Impression Normal to Direction of Rolling	Ball Impression in Direction of Rolling
Below 175	0.515	0.505
Above 175	0.490	0.461

Several checks have been made against the application of this formula to plain carbon steels in both the "as rolled" and in the heat treated condition. The steels tested ranged in carbon from 0.10 to 1.20 per cent. The average error was 3.3 per cent. Checking against the S.A.E. tables for S.A.E. 1035 and 1045 gave average errors of 0.8 and 1.5 respectively. The summary of results showing the average error from Dillner's formula for plain carbon steels is as follows:

Steel Per Cent Carbon	Quench Medium	Average Error Per Cent	Source of Data
0.10 to 1.20	Oil and Water	3.3	Gough
S.A.E. 1035	Water	0.8	S.A.E. Tables
S.A.E. 1045	Oil	1.5	S.A.E. Tables

It is seen from the foregoing that a very satisfactory correlation between Brinell hardness and ultimate strength may be made when Dillner's formula is applied in the case of either normal or heat treated plain carbon steels.

In a number of cases in practice, the application of the Brinell hardness tests is not nearly as convenient as is the Rockwell machine. Unfortunately, comparatively little data is yet recorded in terms of Rockwell hardness, although this machine is rapidly being adopted in industry. It therefore becomes necessary to find the most reliable conversion scale by means of which Rockwell hardness may be changed over to Brinell hardness. When this is done, Rockwell hardness may be converted to terms of ultimate strength or even, as we will see later, to terms of fatigue strength, with an accuracy sufficient for ordinary engineering purposes.

Relation between Rockwell and Brinell Hardness

As in the case of the relationship between Brinell hardness and

ultimate strength, a number of tabulations, formulae and graphs are available for the conversion of Rockwell to Brinell hardness and vice versa. The question arises as to which of these is the more accurate. In order to determine this, conversion data from a number of sources were tabulated, the average taken, and the table approaching nearest to the average taken as the most nearly correct. This is admittedly a crude method of solving the problem. The result of the comparison of the several scales investigated was that the "Conversion Data, Rockwell-Brinell, Rockwell Tester Direction Book, W-M – 16" gives values closest to the average of the scales studied. It is proposed to adopt this scale in subsequent calculations.

The relationship between Rockwell hardness and ultimate strength was computed by using Dillner's formula and the Rockwell-Brinell scale mentioned above. From the tabulation, the relation between Rockwell hardness and ultimate strength may be obtained for plain carbon steels in both the normal and heat treated condition.

Estimation of the Fatigue Limit of Plain Carbon Steel from the Ultimate Strength Value

The importance of the fatigue limits of steels is being recognized more and more strongly in engineering and metallurgical practice. In many cases, although such knowledge is desired, the cost, in time and money, of making standard fatigue tests is unjustified or else the equipment necessary is not available. In such cases, some workers have obtained a rough estimate figure by multiplying the ultimate strength by 0.5 and calling the result the fatigue limit.

Little information seemed to be available regarding the accuracy of this figure, nor was it plain whether or not the factor could be applied to steels in the heat treated condition. No data, in simple forms, was available regarding the effects of the proportions of elements in the steel on the fatigue ratio or regarding the effects on the ratio of the tempering temperature applied to hardened steels. An attempt was therefore made to correlate a limited amount of data so that at least tentative factors could be made available.

In "The Fatigue of Metals," by H. J. Gough, 1926, pages 284 to 299, a considerable amount of data has been assembled. On page 282, the author states:

Table I

Rockwell-Brinell-Ultimate Strength Relationship

Rockwell Number	Brinell Number	Ult. Strength lbs. per sq. in.	Rockwell Number	Brinell Number	Ult. Strength lbs. per sq. in.
B 48	90	46,400	B 99	235	115,000
B 49	92	47,400	B 100	242	118,500
B 50	93	47,900	....	...	.....
B 51	95	48,900	....	...	.....
B 52	96	49,500	C 20	216	106,000
B 53	97	50,000	C 21	222	108,900
B 54	98	50,500	C 22	228	112,000
B 55	100	51,500	C 23	234	114,700
B 56	101	52,000	C 24	240	117,500
B 57	103	53,000	C 25	246	120,500
B 58	104	53,500	C 26	252	123,500
B 59	106	54,600	C 27	258	126,500
B 60	107	55,100	C 28	265	130,000
B 61	108	55,600	C 29	272	133,000
B 62	110	56,600	C 30	280	137,200
B 63	112	57,600	C 31	288	141,000
B 64	114	58,600	C 32	296	145,000
B 65	116	59,700	C 33	304	149,000
B 66	117	60,300	C 34	313	153,000
B 67	119	61,300	C 35	322	158,000
B 68	121	62,300	C 36	331	162,000
B 69	123	63,300	C 37	340	167,000
B 70	125	64,400	C 38	350	171,500
B 71	127	66,500	C 39	360	176,500
B 72	130	67,000	C 40	370	181,200
B 73	132	68,000	C 41	381	187,000
B 74	135	69,000	C 42	392	192,000
B 75	137	70,500	C 43	403	197,500
B 76	139	71,500	C 44	414	202,500
B 77	141	72,500	C 45	425	208,000
B 78	144	74,000	C 46	436	214,000
B 79	147	75,600	C 47	447	219,000
B 80	150	77,200	C 48	458	224,000
B 81	153	78,800	C 49	470	230,000
B 82	156	80,300	C 50	482	236,500
B 83	159	81,500	C 51	494	242,000
B 84	162	82,700	C 52	506	248,000
B 85	165	84,000	C 53	518	254,000
B 86	169	85,200	C 54	530	260,000
B 87	172	86,500	C 55	542	266,000
B 88	176	87,700	C 56	555	272,000
B 89	179	89,000	C 57	568	278,000
B 90	185	90,600	C 58	581	284,000
B 91	190	93,000	C 59	594	291,000
B 92	195	95,500	C 60	607	297,000
B 93	200	98,000	C 61	621	304,000
B 94	205	100,500	C 62	635	311,000
B 95	210	103,000	C 63	650	318,000
B 96	216	106,000	C 64	665	326,000
B 97	222	108,900	C 65	682	334,000
B 98	228	112,000	....	...	.....

"Results of tests on 136 metals are included; the number of heat treatments for each material investigated varying from one to thirteen, representing 247 different materials from a mechanical point of view."

The author also states that the physical data was obtained by him from the following sources: National Physical Laboratory, England; Illinois Engineering Experiment Station, U. S. A.; U. S.

Naval Engineering Experiment Station, L. Aitchison, W. A. Gibson, B. P. Haigh, W. H. Hatfield, F. C. Lea, P. D. Merica, R. G. Waltenberg, A. S. McCabe, and R. R. Moore. The basic data from which my calculations have been made has been bodily lifted from the "Fatigue of Metals," but has been rearranged and recalculated. It is felt that the original data is from reliable sources and that the results which I am presenting are accurate as far as the limited number of specimens allow.

Gough, in "The Fatigue of Metals," pp. 138-146, treats of the matter of the relationship between limiting stress and ultimate stress in some detail and states as follows:

> "To sum up—over the whole range of sound wrought ferrous metals, a general relation appears to exist between the limiting stress for reversed bending stresses and the ultimate tensile strength; the average value of limiting stress to ultimate stress (denoted by η) being 0.46 for a range of ultimate strengths of 19/130 tons per square inch (42,500 to 291,000 pounds per square inch); this ratio may, however, be as high as 0.6 or as low as 0.35."

Of course, a factor varying from 0.6 to 0.35 cannot be used even for purposes of estimation, but it is believed that, if certain conditions are taken into consideration, a useful correlation can be found.

Study of Gough's data revealed the following facts in connection with carbon steels:

(a) In normal or annealed plain carbon steels, carbon is the only element ordinarily present which affects the ratio between ultimate strength and fatigue strength. Even cold-rolled steel does not show an abnormal ratio. In connection with the study of the effects of the presence of the elements other than carbon, the steels considered contained from 0.11 to 1.16 per cent manganese, from 0.030 to 0.090 per cent sulphur, from 0.008 to 0.070 per cent phosphorus, and from 0.007 to 0.44 per cent silicon.

(b) If the range of carbon steels in the normal condition is divided into three factor groups depending on carbon content, a good correlation between ultimate strength and fatigue strength may be obtained.

The factor groups and factors, together with the percentage

errors which may be expected from the estimates, are shown in Table II.

Table II

Ultimate Strength—Fatigue Strength Factors

NORMALIZED AND ANNEALED STEELS

Carbon Range Per Cent	Factor	Expected Error Per Cent
0.10 to 0.35	0.454	3.4
0.36 to 0.65	0.426	1.8
0.66 to 1.20	0.35	2.2

When carbon steels, in the heat treated condition, are considered, a different set of factors must be used. The factor groups and factors suggested are shown in Table III.

Table III

Ultimate Strength—Fatigue Strength Factors

OIL AND WATER-QUENCHED CARBON STEELS

Quench Medium	Carbon Range Per Cent	Factor	Expected Error Per Cent
Oil	0.10 to 0.35	0.40	5.6
Water	0.10 to 0.35	0.426	8.0
Oil or Water	0.36 to 0.45	0.41	5.5
Oil or Water	0.50 to 0.65	0.53	2.9
Oil	0.66 to 1.20	0.48	4.9

The data given in Tables II and III may be applied as follows: Having the ultimate strength of the steel in question in pounds per square inch, this figure is multiplied by the appropriate factor as given in the tables and an estimate of the fatigue strength of the steel is obtained within the estimated percentage error shown.

Chromium-Nickel Steels

Of the alloy steels used in machine construction work, the chromium-nickel series is probably one of the most important. Attention was therefore directed toward the possible application of the methods, which have been described for carbon steels, to steels of this series.

Relation of Brinell Hardness to Ultimate Strength in Chromium-Nickel Steels. It was of interest to find if Dillner's formula, which was used for the plain carbon steels, could be applied to chromium-nickel steels, or if some other formula, specially designed for the purpose, would give more accurate results.

Bullens states[1]: "The following equation connecting strength and Brinell hardness has been computed (R. R. Abbott, A. S. T. M., Vol. IV, Part II, 1915, p. 43 et seq.) from several hundred tests made with high chromium-nickel steel (3.5 per cent nickel and 1 per cent chromium) of different carbon content and heat treated to bring out all possible physical properties." Abbott's formula for chromium-nickel steels is

$$M = 0.71\ B - 33$$

where M = maximum strength (1000 pounds per square inch)
B = Brinell hardness number

After testing out both Abbott's and Dillner's formulae on the S.A.E. 3120, 3130, and 3140 tables, a modification of Abbott's formula is suggested.

$$M = 0.656\ B - 33$$

It should be noted, however, that Abbott's formula was designed for the high chromium-nickel series of steels.

The average errors obtained from Abbott's, modified Abbott's and Dillner's, formulae, are shown in Table IV.

Table IV
Summary of Errors—Abbott's and Dillner's Formulæ

Steel S.A.E.	Quench Medium	Average Errors: Abbott's pounds per sq. in.	Abbott's % Error	Modified Abbott's pounds per sq. in.	Modified Abbott's % Error	Dillner's pounds per sq. in.	Dillner's % Error
3120	Oil	+ 7,000	....	1,800	1.8	−2,900	2.9
3120	Water	+10,000	....	3,200	2.9	−3,500	3.5
3130	Oil	+12,000	....	3,700	3.2	−4,100	3.6
3130	Water	+14,000	....	2,600	2.1	−5,500	4.5
3140	Oil	+20,000	....	5,900	4.4	−6,100	4.5
3140	Water	+25,000	....	10,000	7.0	−3,600	2.5

After considering this tabulation, it is suggested that the modified Abbott's formula be used. It is then necessary to construct a tabulation giving the relationship between Rockwell-Brinell and ultimate strengths for the low nickel-chromium steel series. Such a tabulation is shown in Table V.

Ultimate Strength Fatigue Strength Relationship for Chromi-

[1] D. K. Bullens, "Steel and Its Heat Treatment," 1918, p. 363.

Table V
Rockwell-Brinell-Ultimate Strength Relationship
For Chromium-Nickel Steels (Heat Treated)

Rockwell Number	Brinell Number	Ult. Strength lbs. per sq. in.	Rockwell Number	Brinell Number	Ult. Strength lbs. per sq. in.
B 75	137	57,000	C 30	280	151,000
B 76	139	58,200	C 31	288	156,000
B 77	141	59,500	C 32	296	161,000
B 78	144	61,500	C 33	304	166,500
B 79	147	63,500	C 34	313	172,500
B 80	150	65,500	C 35	322	178,000
B 81	153	67,400	C 36	331	184,000
B 82	156	69,300	C 37	340	190,000
B 83	159	71,300	C 38	350	197,000
B 84	162	73,300	C 39	360	203,000
B 85	165	75,300	C 40	370	210,000
B 86	169	78,000	C 41	381	217,000
B 87	172	80,000	C 42	392	224,000
B 88	176	82,500	C 43	403	231,000
B 89	179	84,500	C 44	414	238,000
B 90	185	88,300	C 45	425	246,000
B 91	190	91,800	C 46	436	253,000
B 92	195	95,000	C 47	447	261,000
B 93	200	98,200	C 48	458	267,000
B 94	205	101,500	C 49	470	275,000
B 95	210	105,000	C 50	482	283,000
B 96	216	109,000	C 51	494	291,000
B 97	222	112,500	C 52	506	299,000
B 98	228	116,700	C 53	518	307,000
B 99	235	121 000	C 54	530	315,000
B 100	242	126,000	C 55	542	323,000
			C 56	555	331,000
C 20	216	109,000	C 57	568	340,000
C 21	222	112,500	C 58	581	349,000
C 22	228	116,700	C 59	594	357,000
C 23	234	120,500	C 60	607	363,000
C 24	240	124,500	C 61	621	375,000
C 25	246	128,500	C 62	635	383,000
C 26	252	132,000	C 63	650	393,000
C 27	258	136,000	C 64	665	403,000
C 28	265	141,000	C 65	682	415,000
C 29	272	145,500			

um-Nickel Steels. Attempts to obtain a factor relationship between the ultimate strength and fatigue strength of chromium-nickel steels was not successful. This may have been due to the very small amount of base data available. It is possible that some relationship does exist. In the few cases investigated, very discordant results were obtained, and no correlation could be made.

Merit Index

In attempting to apply the values obtained from fatigue tests to problems of machine and engineering equipment design and metallurgy, a number of troublesome thoughts come to mind. Where heavy duty has to be met, it is desirable to use steel having a high limiting or fatigue strength. It would seem from the preceding discussion that this could be easily accomplished by using a steel

having a high carbon content, or else a steel having a medium carbon content and subjecting it to a drastic heat treatment to produce high ultimate strength.

In either case, it is well known that a steel of low ductility, as measured by percentage elongation, would result and also it is known that the steel would fail by snapping off short. This leads directly to the conclusion that the application of high ultimate strengths, and therefore high fatigue strengths, is limited by the ductility which can be obtained along with these values.

It seems probable that the amount of bending to which the article is subjected, under load, limits the strength that can be used. These considerations have led to the use of heat treated low carbon steels in such apparatus as oil well sucker rods, because when low carbon steels are properly heat treated, the ultimate strength, and consequently the fatigue strength, can be very materially increased without much decrease in ductility, as measured by percentage elongation.

Under the conditions which have been stated, it is of interest to investigate a method of valuation of steel in which elongation and reduction of area are taken into account. Such a method is offered by J. D. Cutter[2].

Cutter suggests a "merit index" which is an expression used to approximate the work done in fracture; that is, the "toughness" of the steel. The index is as follows:

$$\text{Merit Index} = \frac{\dfrac{\text{Tensile Strength} + \text{Elastic Limit} \times \text{Elongation (\% in 2 in.)}}{2}}{100 - \text{Reduction of Area (Per Cent)}}$$

The formula for merit index was applied to a number of the S.A.E. steel tables, and a graphic chart prepared in which merit index was plotted as ordinates and ultimate strength as abscissae. (Fig. 1.) A contemplation of the curves leads to the following conclusions if the figures for merit index are any measure of resistance to fracture.

(1) Where high fatigue strength and at the same time, resistance to fracture (or toughness) is desired, the steel should be water-quenched and tempered rather than oil-quenched and tempered.

(2) If it is decided that the object should possess a certain

[2]J. D. Cutter, "Suggested Method for Determining Comparative Efficiency of Certain Combinations of Alloy Steels," TRANSACTIONS, American Society for Steel Treating, Vol. 1, 1920, p. 188.

minimum percentage elongation, for instance 20 per cent, several options are open, but the water-quench will give a higher fatigue strength and higher merit index.

(3) In the case of chromium-nickel steels, as well as plain carbon steels, water quenching produced a much greater resistance to failure by fracture than does oil quenching when the same tensile strength is produced by tempering.

(4) In every case of oil-quenched steel, the merit index

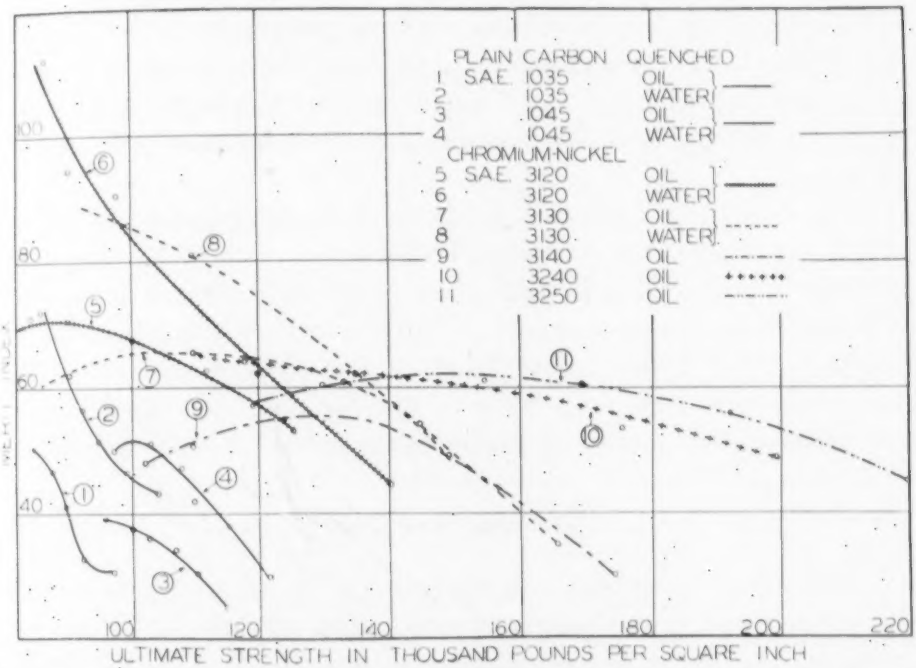

Fig. 1—Merit Index—Ultimate Strength Curves for Plain Carbon and Chromium-Nickel Steels Variously Treated.

reaches a maximum and then shows a decrease with a 1300-degree Fahr. temper. This does not occur with water quenching. In water-quenched steels, the highest merit index is obtained with the highest tempering temperature. This would indicate that oil-quenched steels should not be tempered over 1200 degrees Fahr.

(5) An important point is brought out that an 800-degree Fahr. draw gives a uniformly low merit index. This is particularly true in the case of water-quenched steels. It would seem better to sacrifice some strength and draw at a temperature not lower than 900 degrees Fahr.

(6) The curves (Fig. 1) for the various classes of steels fall

into three distinct zones: (a) the curves for oil and water-quenched plain carbon steels (curves 1, 2, 3, and 4), (b) the curves for the low nickel steels, S.A.E. 3120, 3130, and 3140 (curves 5 to 9), (c) the curves for the high chromium-nickel steels, S.A.E. 3240 and 3250 (represented by curves 10 and 11).

(7) The plain carbon steels, curves 1 to 4, show the small range of tensile properties obtainable from these steels and also that the small changes in tensile strength reflect large changes in merit index. In other words, the curves assume a steep angle. The superiority of water quenching over oil quenching is brought out very plainly. The water quench curves 2 and 4 lie well above the oil quench curves 1 and 3. This means that for a given strength, the water quench steel has a much greater resistance to failure by fracture.

(8) In the low chromium-nickel series, represented by curves 5 to 9, one of the most striking things is the remarkable properties of water-quenched S.A.E. 3120 steel. This steel gives a large range of properties, and as compared with a plain carbon steel, has an extremely high resistance to fracture for a given strength. This steel is not very commonly used except for case hardening, but the possibility of its use for machine parts is well worth considering.

Regeneration Tests

One of the problems confronting the operator of the smaller industrial shops is the matter of inspection of steel, as he receives it, for its quality as regards ability to give results after heat treatment. Many problems of this nature can be taken care of by the use of the so-called "regeneration" test. By the word "regeneration," is generally meant the ability of a steel to absorb its free ferrite into solid solution when heated through its upper critical range. Steels which, for some reason, will not do this are often called "abnormal" steels.

Ordinary regeneration tests are easily carried out if a heat treating furnace and an instrument for testing hardness are at hand. In carrying out these tests in a plant, it is advisable to adopt a certain standard size of test piece so that the effects of mass be always constant.

If a series of test pieces are heated for a constant time at increasing temperatures, say 1300, 1400, 1500, 1600, and 1700 degrees

Fahr., water-quenched, and tested for hardness, a normal steel will show a rapid increase in hardness as the quench temperature is increased. A quench temperature will be reached above which a decrease in hardness will be obtained. The temperature giving the greatest hardness is the temperature to which the steel should be heated as a preliminary to almost all subsequent heat treatment operations. This will be true for annealing, grain refinement, or heating for hardening.

Tentative suggestions for the conduct of regeneration tests are as follows:

(a) Steels which give proper reactions on heat treatment should show a minimum Brinell hardness of 500 when quenched in cold water from the proper temperature.

(b) It is suggested that the following quench temperatures be used for carbon steels:

Carbon Content Per Cent	Standard Quench Temperature Degrees Fahr.
0.15 to 0.30	1600
0.30 to 0.40	1550
0.40 to 0.60	1500

Alloy steels should be quenched from 1500 degrees Fahr.

(c) The test bars should not exceed 1″ square section. Preferably they should be about 1″x¾″x3″ long. If the steel, as received, has a smaller section, pieces about 2″ or 3″ long may be used for the test.

(d) Steel specimens may be quenched from the standard temperature, reheated and requenched, at least four times, without affecting the quench hardness.

(e) A heating time of 30 minutes at temperature is suggested.

(f) A quench water temperature of lower than 80 degrees Fahr. is recommended. Tests have shown, however, that hardness does not drop off until the quench water temperature reaches about 100 degrees Fahr.

The regeneration test offers a method of testing steel quality. Having established the proper quench temperature, and maximum hardness for a certain class of steel which has given satisfactory results in the past, it is a simple matter to test a new lot of steel for its ability to regenerate and therefore to heat treat properly. The possession of an instrument for determining hardness enables the

operator to determine the quality of his steel before he spends money on the machining and heat treatment of a finished article.

Macro-etching

Before closing this paper, it is felt that some consideration should be given to a simple and extremely useful test that can be applied to steel with the use of but little equipment. It is believed that many operators could gain much useful information if they made a few macro-etch tests on their steel products.

Probably the most useful etching reagent is ammonium persulphate solution, which should be applied to the smooth surface to be tested with a tuft of cotton wool. Application with a rubbing action for about five minutes usually suffices to develop a satisfactory etched surface.

Conclusion

An attempt has been made to demonstrate that with simple and inexpensive equipment, the operator of the small heat treatment and machine shop can readily obtain much information regarding his raw materials and his product.

Having at hand an instrument for hardness testing, and the use of one of his furnaces, he may readily obtain the following:

(a) A close estimate of the tensile strength of steel.
(b) An estimate of the fatigue strength of steel within limits close enough for engineering purposes.
(c) A valuation of the quality of his raw materials as regard their ability to heat treat.

ANNEALING STEEL SHEETS IN CONTINUOUS GAS-FIRED KILNS

By J. B. Nealey

Abstract

The increasing use of long furnaces or kilns, which are automatic and continuous in operation, for heat treating steels is resulting in progressive betterment in their design and control. A description of two modern gas-fired kilns, used in white and black annealing respectively, follows. These are a part of the equipment of the new plant of the Youngstown Sheet and Tube Company of East Chicago, and each is of sufficient capacity to handle the entire output of the plant without slowing down operating schedules.

MODERNIZING the heat treatment of steel along with mass production has started a movement from the periodic to the continuous furnace that bids fair to eliminate the former where production is great enough to warrant the installation of the latter. Close temperature and atmospheric control are absolute requirements to perfect heat treating and gas meets these requirements in the fullest degree.

Among the steel mills using gas-fired continuous furnaces or kilns for annealing steel sheets is the Youngstown Sheet and Tube Co. of East Chicago, Ind., which has recently built one of the most modern and up-to-date tinplate plants in the country. In both the black and white annealing departments is located a huge furnace or kiln capable of handling the entire output as it passes through without in any degree delaying the production time schedule of the entire plant.

After passing through the rolling mills, squaring shears and black pickle the sheets are packed for black annealing in one of these continuous furnaces, which is 338 feet long, 20 feet wide and 11 feet high. It is of brick construction, suitably stayed and of the semi-muffle type, the muffles being of fireclay. The former practice of piling the sheets in boxes is still retained and the stand-

The author, J. B. Nealey, is associated with the American Gas Association of New York City. Manuscript received May 2, 1929.

ard type of box that was used in the periodic furnaces, is in vogue. The sheets are piled 42 inches deep on the bases of these boxes or pots, two piles to a base. The cover is then put on and sanded to exclude the air.

A track runs through the furnace and another track runs parallel to it but on the outside of the furnace, and close to it. Cars with tops 102 inches by 69 inches are operated on this track and the charged boxes are picked up by an overhead traveling crane and placed on them. There is a compartment at each end of the furnace for charging and discharging, respectively. A door in the former is opened, a car is pushed in by truck, and the door closed, leaving the car on the track that runs through the furnace.

Another door is opened directly into the furnace and a hydraulic ram pushes the car in. At the same time the entire line of cars or furnace charge is pushed along, the first one being pushed into the discharging compartment. With these two compartments, cold air, which would upset the temperature cycle, is excluded. A carefully worked out temperature gradient is maintained in this unit which is roughly divided into three zones, preheating, soaking and cooling.

The furnace is kept at 800 degrees Fahr. (425 degrees Cent.) at the charging end and this temperature gradually rises until 1400 degrees Fahr. (760 degrees Cent.) is obtained in the soaking zone. From here it gradually drops until it reaches 800 degrees Fahr. (425 degrees Cent.) at the discharging end. The total time for a box of sheets to pass through this unit is 32 to 33 hours and 15 hours of this time is passed in the soaking zone. The unit will hold 53 cars at a time, two pots to the car, 10,000 pounds of sheets to the pot, and the capacity of the furnace is 400 tons of sheets in 24 hours (40 cars per day capacity).

The muffles are located in the center, one on each side, and into each of these fire ten gas burners spaced 15 feet apart. These muffles terminate about 45 feet from the first of two offtake ports, and are open at this end. The exhaust gases pass through the muffles until the open ends are reached and then pass directly into the main kiln tunnel, where the gases circulate directly around the pots, until they reach the offtake ports, the first of which is located only 5 feet from the inner discharge door of the furnace.

This arrangement was so designed as to protect the pots and

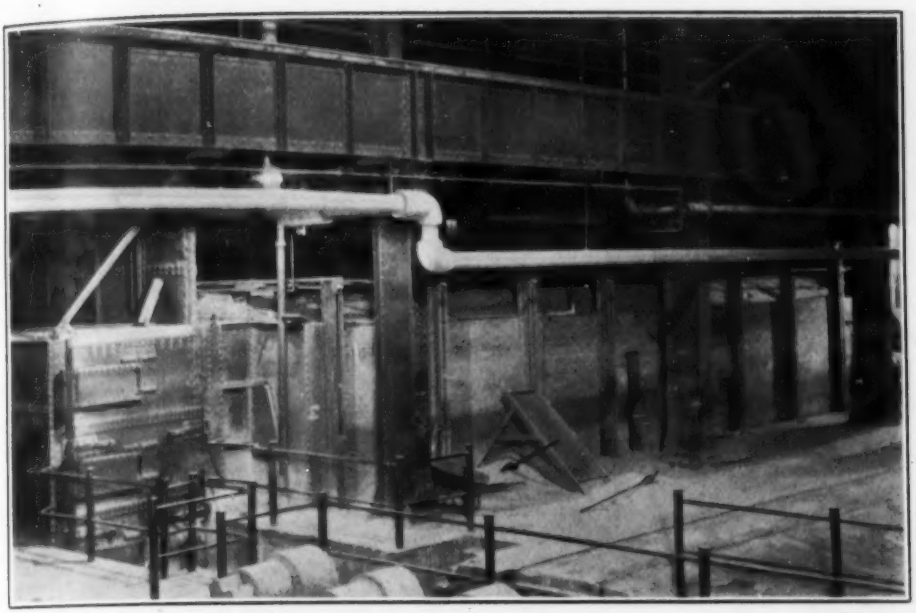

Fig. 1—Photograph Showing Discharge End of Black Anneal Furnace.

plates from direct flame action and to prevent hot spots in the furnace zone. By causing the exhaust gases to travel in a direction opposite to the movement of the work, much of the otherwise waste heat is imparted to the cold incoming work. Thus the temperature of the work is raised considerably before the real heating commences, the flue gas temperatures are lowered by this amount, and the fuel consumption of the unit reduced, all of which materially increase the efficiency of the furnace. Another big advantage lies in the fact that moisture and acid from the pickling and washing are quickly carried away so that staining of the plates is eliminated. The draft is regulated by dampers in vents supplied, and is maintained at half an inch water gage by the aid of draft gages. This control is positive in the face of changes in wind velocity.

Heat regulation is accomplished through a complete and unique control system located in a separate room. In the furnace are 36 thermocouples which are connected to a 36-point switchboard and indicating pyrometer in the control room. In this room also is the control board, about 8 feet long, located on one wall, which has a chart of the furnace divided into sections, just above it.

Each section represents the space occupied by one car and below it is a hook for a tag. Each tag represents a car and on it is written the size and gage of sheets and this row of tags is moved

Fig. 2—Photograph Showing a Loaded Car Going into the Charging Compartment of Black Anneal Furnace.

along one space every time a new car is pushed in and an old one pushed out. The same heat gradient is always maintained but the time cycle must be varied to suit the size and gage of sheets being treated. With the use of the above board considerable flexibility in the heat treatment is attained.

This is evident in the schedules which are made out 24 hours in advance. By this method sheets of several different sizes and gages can be treated on the same schedule.

On each side of the kiln, and located in the last third, is a battery of pipes parallel to the ware, through which cold air is drawn, and these pipes perform the dual functions of reducing the temperature in the cooling chamber and furnishing heated air to the burners. This is the ordinary recuperator principle of utilizing waste heat, adapted to another use.

As the cars come out of the furnace the boxes are lifted off by cranes and deposited in a storage space nearby where they are allowed to cool for 48 hours, or to a temperature of about 200 degrees Fahr. At this time the sand seal is broken, the covers removed and the sheets allowed to cool in the open air for another 48 hours or to room temperature. The packs are next moved by cranes to the inspection department where they are opened, in-

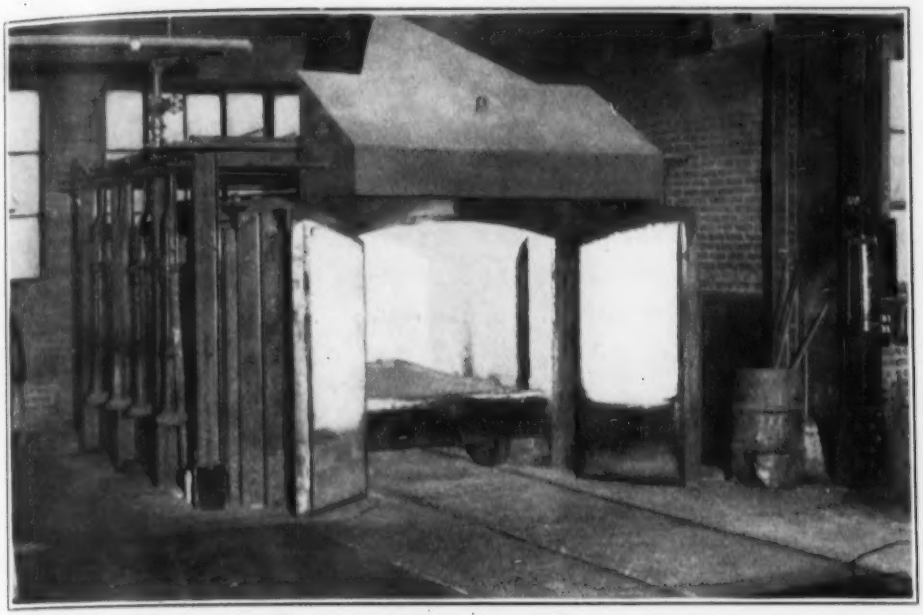

Fig. 3—Photograph of Burn-Out Furnace.

spected and assembled according to orders. The sheets are then put through the cold rolls.

After this rolling the sheets are again packed in box bottoms for the white annealing process. This is accomplished in the same type of continuous furnace as described but smaller, being only 290 feet in length. This heat treatment is somewhat different from the black annealing in that the temperature in the soaking zone is only 1110 degrees Fahr. (600 degrees Cent.) while that at both ends is 600 degrees Fahr. (315 degrees Cent.) The heating period averages 32 hours and the sheets are in the soaking zone for 10 hours.

This furnace will hold 45 cars at a time and each pot is charged with 12,000 pounds of sheets, a total capacity of 408 tons per 24 hours. The boxes after removal are allowed to cool for 48 hours when the covers are lifted off, and the sheets allowed to cool for another period. This unit is heated with 7 gas burners on each side and the same system of control as is employed on the other unit, is used.

A burn-off oven is used to burn the dirt and grease from the tinning machines when they are taken down for repairs. This is built of brick, is 12 feet to a side and 7 feet high, and is heated

with four gas burners on each of two sides. Tracks run into this furnace, and on them cars are operated which hold the machines. The tops of these cars are of brick and the sides of these are so close to continuous projections from the sides of the furnace that most of the heat in the heating chamber is prevented from passing down around the wheels and trucks. This is the same system as is used in the annealing furnaces just described. This furnace is maintained at 1500 degrees Fahr. (815 degrees Cent.) and it takes from 6 to 7 hours for the burn off operation.

Educational Section

These Articles Have Been Selected Primarily For Their Educational And Informational Character As Distinguished From Reports Of Investigations And Research

THE CONSTITUTION OF STEEL AND CAST IRON
SECTION II—PART XI

By F. T. Sisco

Abstract

This installment, the eleventh of the present series, takes up the heat treatment of carburized steel and its effect on the structure. Illustrated by representative photomicrographs, the discussion of heat treatment includes the effect of cooling slowly from the carburizing temperature, quenching directly from the box, quenching to harden the case, and regenerative quenching to harden the case and refine the core. Following this discussion the surface hardening of steel is briefly described. Included in this are the operations of cyaniding, pack hardening and nitriding. The installment closes with a brief view of normal and abnormal carburizing steels.

IN the previous installment we viewed briefly the operation of carburizing or cementation and saw that it consisted of heating steel above the critical range in contact with a carbonaceous material such as charcoal. In the presence of air or some energizer carbon monoxide is formed which penetrates the steel and deposits carbon to form a high carbon outer zone. The carbon which is about 1.00 per cent at the surface gradually decreases until approximately $\frac{1}{16}$ to $\frac{1}{8}$ inches from the surface the carbon percentage is that of the original steel.

All carburized steel objects are heat treated. There would be no reasons for producing a high carbon surface on a low carbon piece unless we take advantage of the strength, hardness and wear

This is the twenty-first installment of this series of articles by F. T. Sisco. The several installments which have already appeared in TRANSACTIONS are as follows: June, July, August, September, November, 1926; January, February, April, June, August, October, 1927; February, April, June, November, 1928; January, March, May, June, July, 1929.

The author, F. T. Sisco, a director of the society, is chief of metallurgical laboratory, Air Corps, War Department, Wright Field, Dayton, Ohio.

resistance of the high carbon steel. To obtain these desirable properties from the carburized piece it must be heat treated.

The Heat Treatment of Carburized Steel

In the heat treatment of a carburized steel the high carbon surface must be hardened but at the same time that we secure surface hardness, we must also take steps to avoid any brittleness in the core. In the heat treatment of a carburized steel we must remember that we are actually dealing with two steels, one is low in carbon, the other, which is in reality but a thin shell around the low carbon core, is a high carbon steel containing between 0.80 and 1.20 per cent carbon.

In addition to the fact that we have in truth two distinct steels to be treated, we must in this heat treatment refine the grain. In commercial carburizing practice the material has been heated well above the critical range and for a considerable length of time. Under these conditions we must expect that some grain growth will take place. Suppose for example we take a 0.15 per cent carbon steel carburized for 6 hours at 1700 degrees Fahr. This carburization results in a uniform case having a maximum of about 1.00 per cent carbon. If we refer to a heat treatment chart or the iron-carbon diagram, we will see that the critical temperature for the case is about 1320 degrees Fahr. the Ac_1 point. The critical temperature for the low carbon core is approximately 1550 degrees Fahr. the Ac_3 point. Hence the hardening temperature for these two distinct steels is 1380 to 1425 for the high carbon case and 1575 to 1650 for the low carbon core.

To refine the grain of the low carbon core we must heat above the Ac_3 point so that the structure will be changed from ferrite plus a little pearlite to austenite, but in this heating we must be careful not to go so high that excessive grain growth will occur. The first operation in the heat treatment of a carburized steel is, therefore, to heat the material to a temperature of 1575 to 1650 degrees Fahr., hold just long enough for the piece to be heated through and quench, usually in oil. Quenching to refine and toughen the core also serves to harden the case but as the temperature used, 1575 to 1650 degrees Fahr., is 150 to 250 degrees higher than the correct temperature for a 0.90 to 1.00 per cent carbon steel, this quenching has served to coarsen as well as harden the

case. Hence, we reheat the quenched piece to 1375 to 1425 degrees Fahr. and quench again, this time in water. This is followed by tempering at a temperature just high enough to remove the strains introduced during the quenching operations.

Thus we see that in any carburized steel the heat treatment involves two operations, the first is to refine the core, the second is to harden the case. The heat treatment just outlined is more-or-less standard for carburized sections. There are, however, some noteworthy exceptions to the practice described above. One is the heat treatment applied when the case is very high in carbon and contains a relatively large amount of free cementite. When this happens, the steel should be heated above the Ac_{cm} point in order to effect the solution of the excess cementite in the austenite. If the carbon in the case does not exceed 1.10 per cent, at the temperature for refining the core, about 1650 degrees Fahr., the excess cementite will go into solution. If the carbon is higher than this, higher temperatures must be used.

To effect the solution of the excess cementite when the case is high in carbon, a triple quench is sometimes used. The material is carburized at about 1700 degrees Fahr. and is quenched from the carburizing box instead of being cooled slowly. The core is then refined and this in turn is followed by the hardening treatment for the case.

In general, then, the heat treatment recommended for carburized objects where the case does not exceed 1.10 per cent involves three steps. The first one is to cool the material in the box after carburizing until a temperature of approximately 1100 degrees Fahr. or below is reached. The steel is then heated to the proper quenching temperature for a low carbon steel, or approximately 1600 degrees Fahr., followed by quenching in oil. This refines and toughens the core. The last step is to reheat to the hardening temperature for a high carbon steel, or about 1400 degrees Fahr., followed by quenching in water. As this temperature is well below the critical range for the low carbon core, this section of the piece is unaffected by the quench. After the case is hardened it is, of course, tempered at 300 to 400 degrees Fahr. to remove hardening strains. This duplex heat treatment usually recommended for carburized steels is know as the regenerative quench. As already indicated when much free cementite is present due to a high car-

burizing temperature and to a compound which produces this very high carbon surface, the material frequently is quenched first from above the Ac_{cm} line in order to effect solution of the free cementite.

For a great many carburized products refinement and toughening of the core is not necessary. Hence the commercial practice for these includes carburizing at 1625 to 1700 degrees Fahr., followed by cooling in the box. The pieces are then hardened by quenching in oil, water or brine from the proper temperature which varies according to the steel from 1375 to 1475 degrees Fahr. The common practice for carburizing gears and like parts is to carburize at 1600 to 1650 degrees Fahr. and quench in oil directly from the box without the intermediate cooling. This is followed with hardening the case by quenching from 1425 to 1450 degrees Fahr. Heat treatment after carburizing is commonly known as case hardening.

It will be unnecessary to discuss further the commercial heat treatment of carburized products. This is throughly covered in many standard text books on heat treatment. The American Society for Steel Treating has adopted recommended practices for carburizing a number of parts such as camshafts, gears, piston pins and the like, and in addition has assembled much data on practical carburizing[59]. But even though we are not particularly interested in commercial carburizing and the heat treatment of various classes of carburized objects, we are concerned greatly with the effect of these operations upon the structure of the steel.

The Effect of Carburizing and Case Hardening on the Structure of Low Carbon Steel

The effect of carburizing and the subsequent heat treatment is shown by the series of micrographs, Figs. 72 to 80. The specimens from which these photographs were made were prepared as follows: Blocks of an 0.18 per cent carbon steel approximately ½ inch square were machined and packed in a carburizing box with a commercial wood charcoal barium carbonate compound. The box was heated to 1725 degrees Fahr. and held at this temperature for 3 hours. The specimens were then given the following treatment:

[59]Loc. Cit.—p. 179-204.

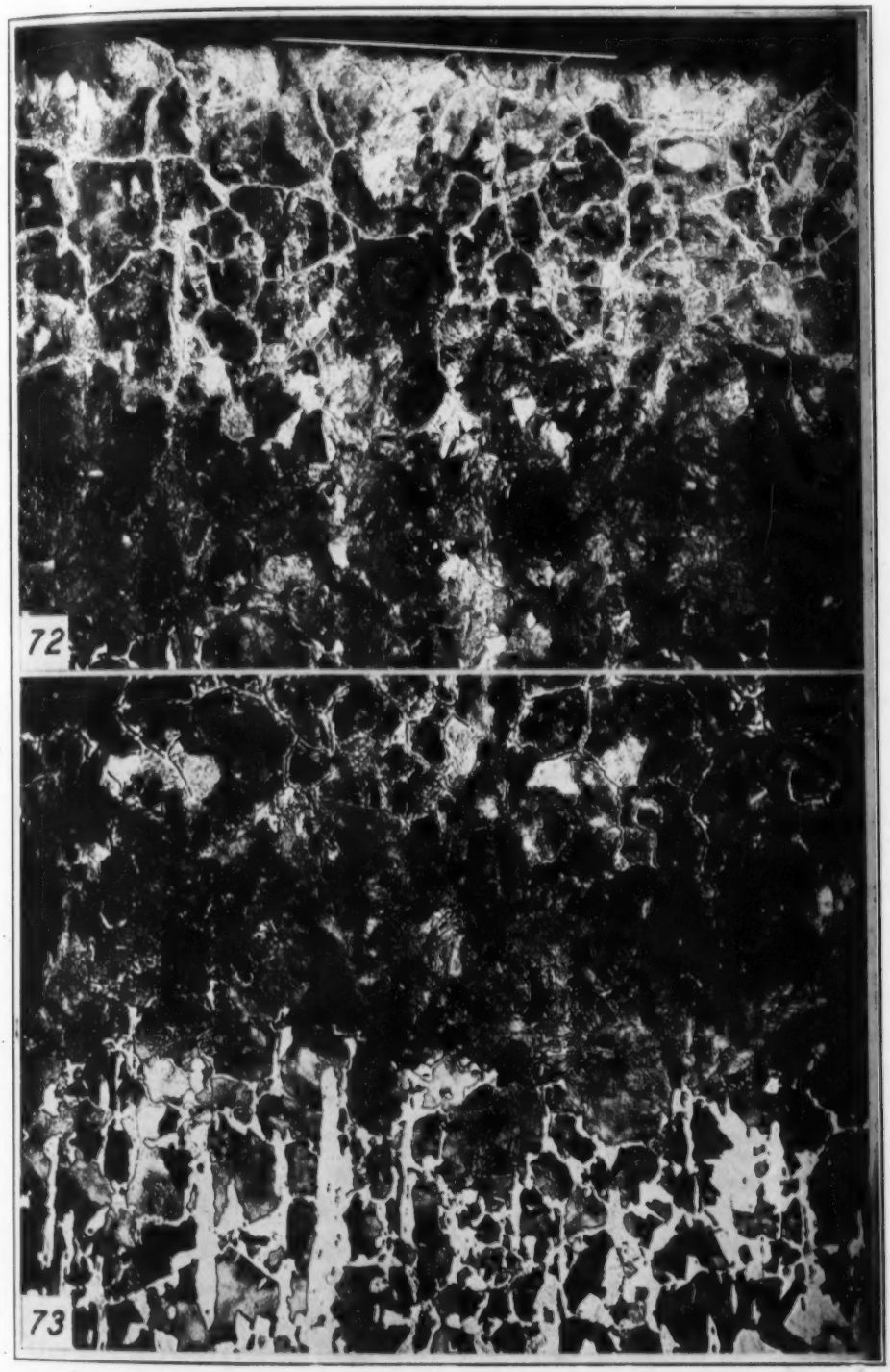

Fig. 72—Low Carbon Steel Carburized Three Hours at 1725 degrees Fahr. and Cooled in Box. Structure of Case. × 100.

Fig. 73—Same Specimen as Fig. 72. Structure of transition zone. × 100. Etched in Alcoholic Nitric Acid.

Specimen No. 1— Cooled slowly in the box to room temperature.

Specimen No. 2— Quenched directly from the box into cold water.

Specimen No. 3— Cooled in box to room temperature, reheated to 1425 degrees Fahr. and quenched in water.

Specimen No. 4— Cooled in box to room temperature, reheated to 1650 degrees Fahr., and quenched in oil. The specimen was then reheated to 1425 degrees Fahr. and quenched in water.

One eighth inch was then removed from one surface of each piece by grinding. The case of all specimens was apparently uniform and was about $\frac{1}{16}$ inch deep. By means of Figs 72 to 80 we can trace the effect of carburizing and the various subsequent heat treatments upon the structure of this low carbon steel.

The structure of the steel after carburizing and slow cooling is shown in Figs. 72, 73 and 74. Fig. 72 shows the case. The high temperature of carburization, 1725 degrees Fahr., has promoted a certain amount of grain growth and has produced considerable laminated pearlite. The laminations are even visible at 100 diameters, which is unusual. These pearlite grains contain some free cementite in addition to the cementite network clearly evident in Fig. 72. The transition zone is shown in both Figs. 72 and 73. This zone is made up of granular and laminated pearlite. It will be noted (Fig. 73) that the carbon has migrated for a considerable distance into the steel, as can be seen by the large pearlite areas which have formed among the ferrite grains near the bottom of the photograph. Fig. 74 is a photograph of the low carbon core in the slowly cooled specimen. This micrograph is included so we can watch the effect of heat treatment upon the core.

Figs. 75 and 76 show the structure of a specimen quenched in cold water directly from the carburizing box. The case (Fig. 75) is martensite made up of coarse needles due to the high quenching temperature. The transition zone which etched dark in Fig. 75 is probably troostite. The structure of the core is shown in Fig. 76. This structure is made up of very large particles of ferrite (white) and troostite or sorbite (dark). This coarse structure is just what we would expect from quenching in water from the high temperature.

The next specimen, No. 3, was cooled in the box and then re-

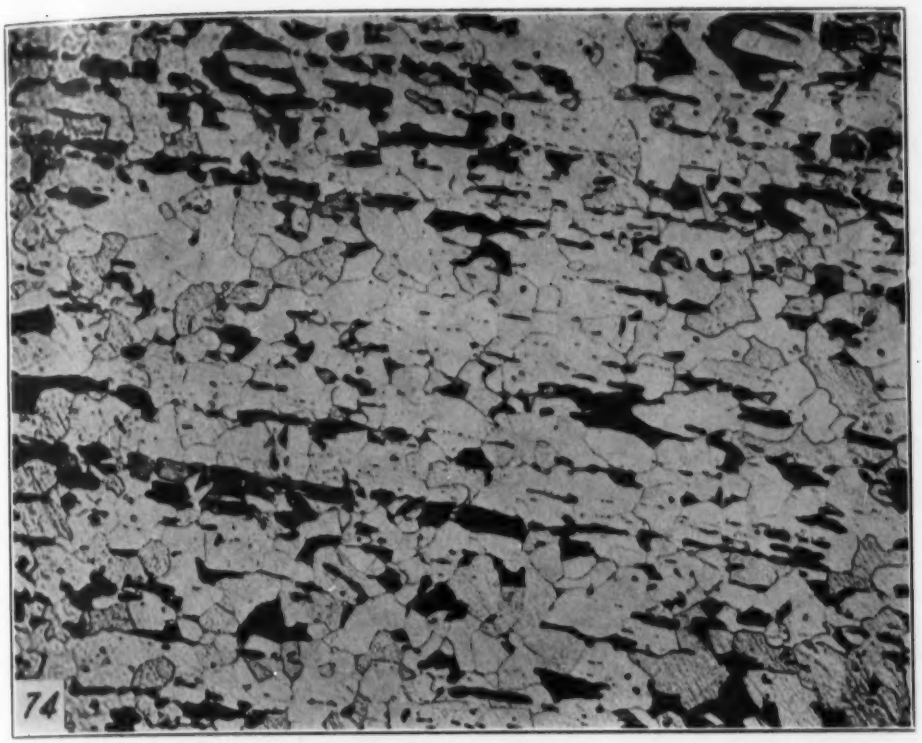

Fig. 74—Same specimen as Fig. 73. Structure of core. × 100. Etched in Alcoholic Nitric Acid.

heated to just above the $Ac_{3\text{-}2\text{-}1}$ point for a high carbon steel and quenched in water. The structure of the case resulting from this single quench is shown in Fig. 77. The austenite has been transformed by the rapid quench into a fine-grained martensite but at the temperature used (1425 degrees Fahr.) the excess cementite which formed a network around the grains has not gone into solution. A case with this structure would be very hard but is also likely to be brittle. The transition zone is a fine-grained troostite. The structure of the core has been affected but little by quenching from this low temperature, as is evident from comparing Fig. 78 with Fig. 74. The carbon-bearing grains in Fig. 78 are now uniform in structure and are finely laminated pearlite verging on the granular. The size of the ferrite grains is the same as in the slowly cooled specimens (Fig. 74).

The effect of the regenerative quench on specimen No. 4 is shown in Figs. 79 and 80. The case is a fine-grained martensite with no evidence of the free cementite network. The martensite structure gradually becomes troostitic about 0.01 inch from the

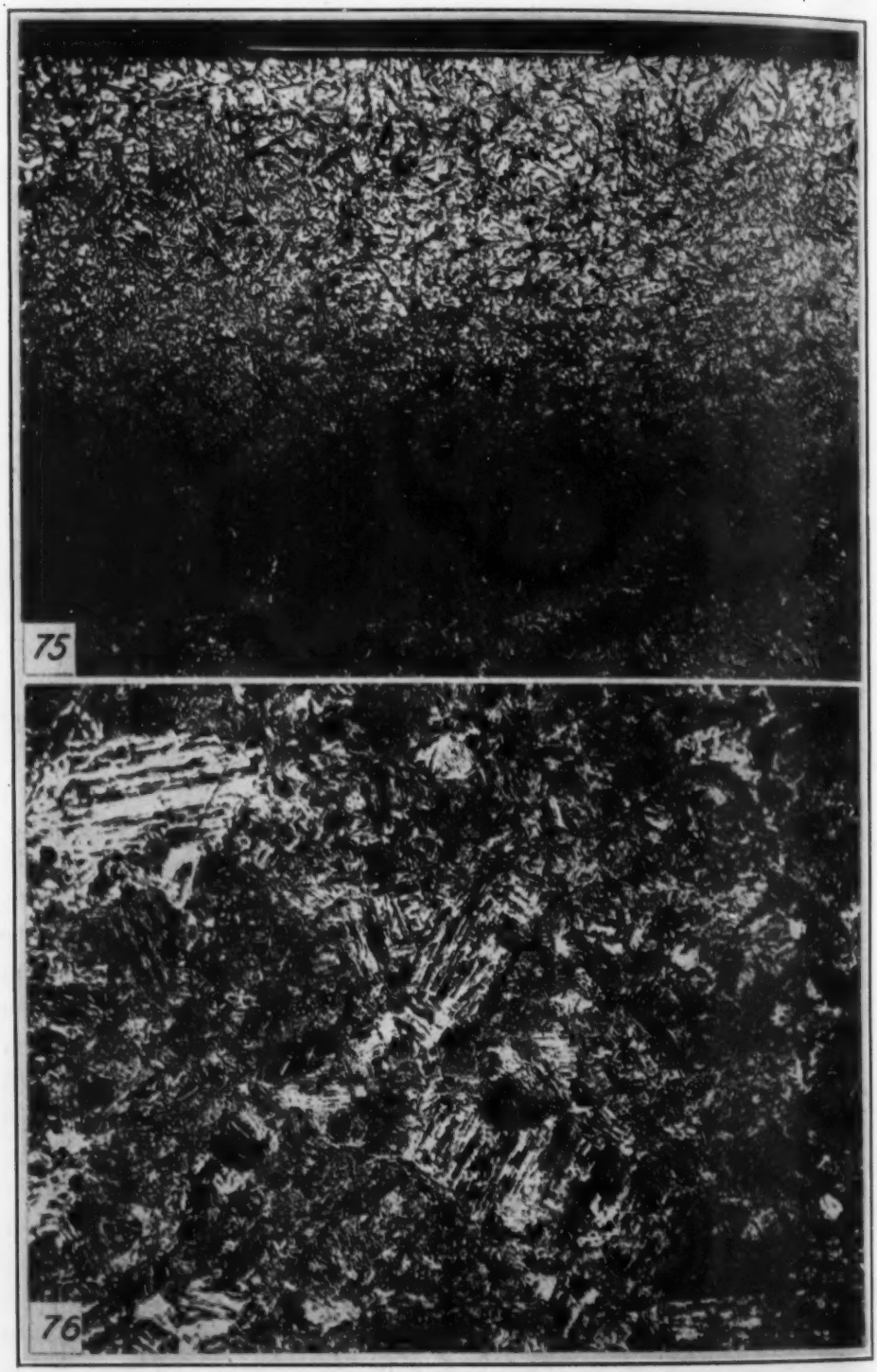

Fig. 75—Low Carbon Steel Carburized Three Hours at 1725 degrees Fahr. and Quenched from Box into Water. Structure of Case. × 100.

Fig. 76—Same Specimen as Fig. 75. Structure of Core. × 100. Etched in Alcoholic Nitric Acid.

edge of the specimen (one inch from the white line in Fig. 79). The core has a desirable fine grain (Fig. 80). When this is compared with the core of the slowly cooled specimen shown in Fig. 74, the effect of quenching in oil from 1650 degrees Fahr. is readily apparent. This structure may also be compared with the core of the specimen quenched directly from the box (Fig. 76).

From these micrographs it is evident that quenching directly from the carburizing box (1725 degrees Fahr.) without further heat treatment results in a very coarse structure in both case and core. On the other hand a single quench from 1425 degrees Fahr. does not refine the core at all, and while it hardens the case does not effect the solution of all of the free cementite. It is quite plain from the illustrations that the regenerative quench given to specimen No. 4, produces an excellent structural condition in both case and core. Had the carburizing temperature been 1650 degrees instead of 1725 degrees Fahr. the specimens could have been quenched in oil directly from the box to refine the core and effect the solution of the free cementite and this followed by quenching from 1425 degrees Fahr. in water to harden the case. These photographs well illustrate the effect of heat treatment and show the advisability (at least for a carburizing temperature of 1725 degrees Fahr.) of using the regenerative quench.

Surface Hardening

It is sometimes desirable for a steel part to be very hard on the surface but at the same time it is not necessary that this hard external zone or "skin" be of any great depth. In this event a method of carburizing is used whereby this hard skin can be obtained quickly and cheaply. The principal method of surface hardening is known as cyaniding. In brief this consists of immersing a low carbon steel in a bath of molten potassium or sodium cyanide maintained at a temperature of about 1550 degrees Fahr. The time of immersion is short, five to fifteen minutes, after which the piece is removed and immediately quenched, either in water or oil. By this method the steel is carburized to a depth of 0.005 to 0.015 inches.

According to the work done by d'Arcambal[60] the steel is both carburized and nitrogenized by this treatment. The hardness is

[60] Transactions, American Society for Steel Treating, Vol. 2, 1922, p. 1112.

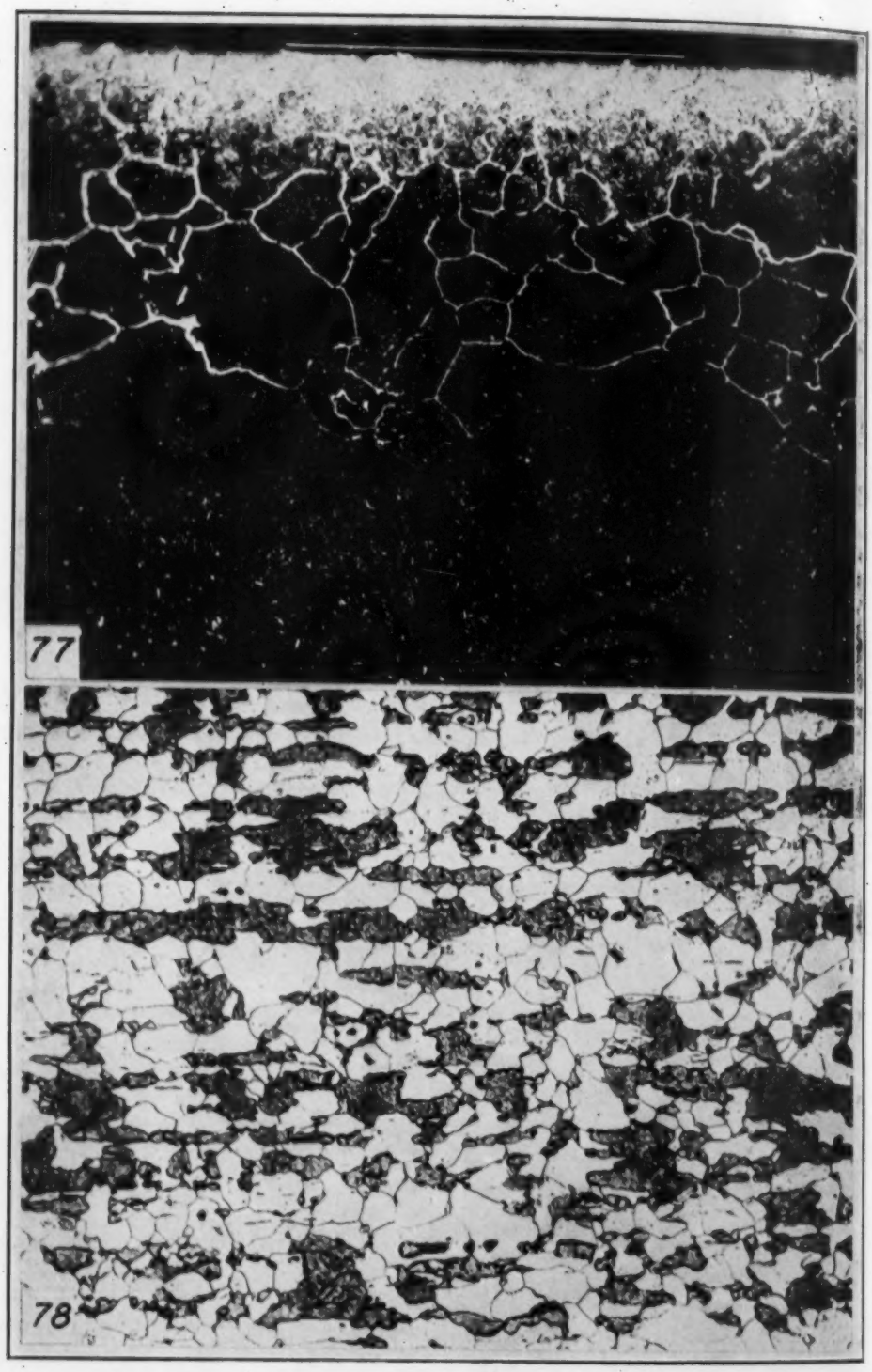

Fig. 77—Low Carbon Steel Carburized Three Hours at 1725 degrees Fahr. Cooled Slowly in Box, then Reheated to 1425 degrees Fahr. and Quenched in Water. Structure of Case. × 100.

Fig. 78—Same Specimen as Fig. 77. Structure of Core. × 100. Etched in Alcoholic Nitric Acid.

due principally to absorbed nitrogen as the carbon in the case is too low to produce file hardness after heat treatment. The highest concentration of carbon and nitrogen is found in the outside layer. d'Arcambal found that in the outside 0.010 inch of the steels he cyanided the nitrogen content ranged from 0.215 to 0.451 per cent. In the next layer of 0.010 inch the nitrogen was below 0.08 per cent. This authority states that the absorbed nitrogen causes greater brittleness in medium and high carbon steels than in steels of low carbon content. For this reason a cyanide bath should not be used as a heating medium for high carbon tool steels.

The structure of a cyanided low carbon steel is shown in Figs. 81 and 82. The specimen shown in Fig. 81 was cyanided for five minutes at 1550 degrees Fahr. and cooled slowly over night in hot lime. The specimen shown in Fig. 82 was cyanided for ten minutes at the same temperature and quenched in water. In Fig. 81 and 82 the white lines indicate the edge of the case.

A variation of the carburizing process which is sometimes used for small tools of high carbon steel is known as pack hardening. In this method the parts are packed in the usual manner in a box with a suitable carburizing compound. The temperature is approximately the same as the hardening temperature for tool steel, 1425 degrees Fahr. The tools are maintained at heat for about two hours or just long enough to produce a thin superficial case. The material is then quenched directly from the box into water or oil. It is claimed that this method of superficial hardening results in a more uniform hardness and that in most cases the same surface hardness can be produced by quenching in oil as ordinarily results from quenching high carbon steel in cold water.

A recently developed method of surface hardening is known as nitriding. The process depends upon the fact that certain alloy steels containing about 1.0 per cent aluminum will absorb nitrogen which goes into solid solution instead of existing as the brittle iron nitride. The details of this process are so well known and have received so much attention recently that it is unnecessary to repeat them here. In brief the process consists of heating the finished steel parts in an atmosphere of ammonia for periods ranging from two to ninety hours. The temperature for nitriding is 875 to 975 degrees Fahr. Desirable physical properties in the core are obtained by heat treating before nitriding as the steels are not treated

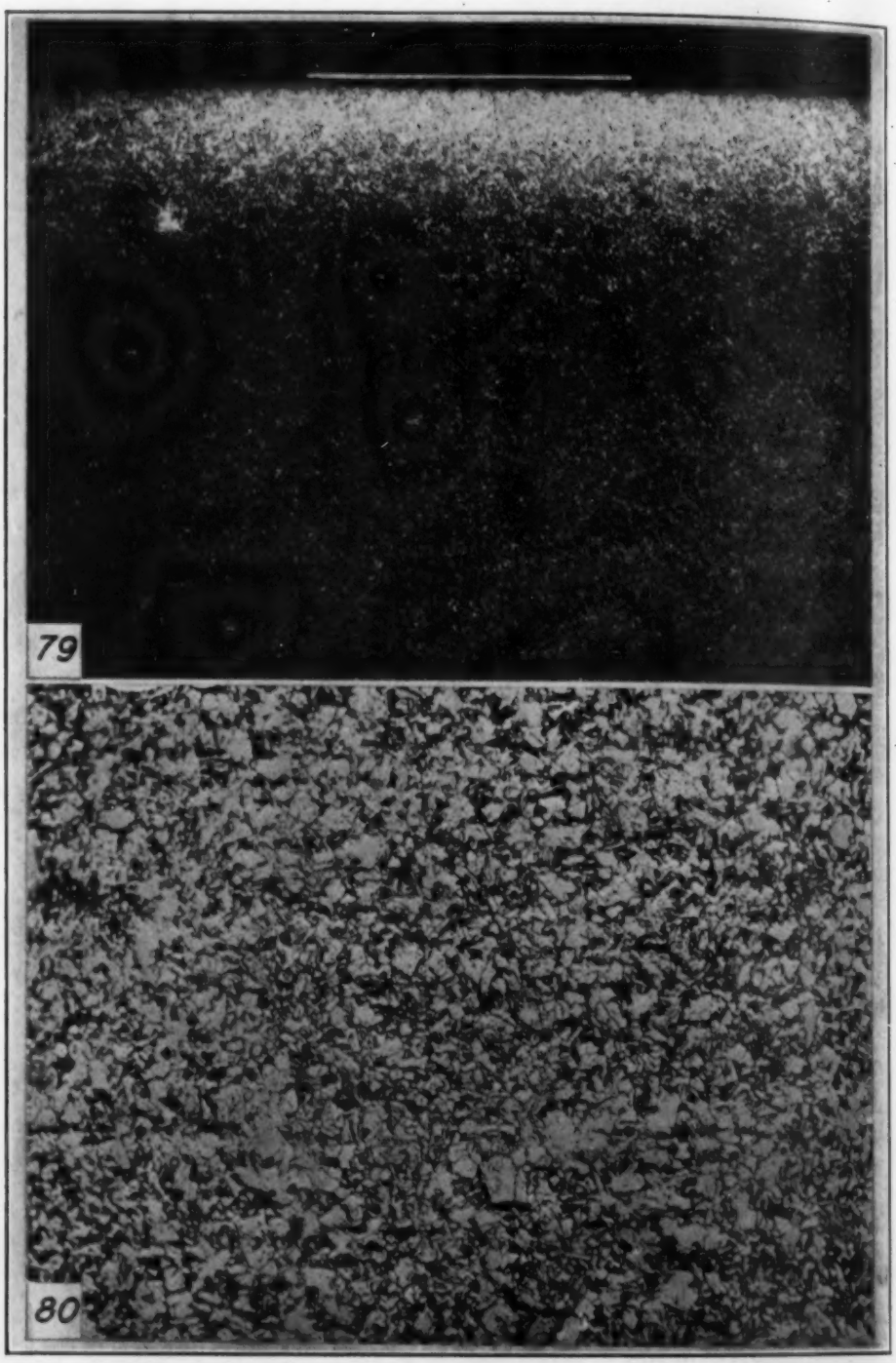

Fig. 79—Low Carbon Steel Carburized Three Hours at 1725 degrees Fahr. Cooled Slowly in Box; Reheated to 1650 degrees Fahr. and Quenched in Oil then Reheated to 1425 degrees Fahr., and Quenched in Water. Structure of Case. × 100. Etched in Alcoholic Nitric Acid.

Fig. 80—Same Specimen as Fig. 79. Structure of Core. × 100. Etched in Alcoholic Nitric Acid.

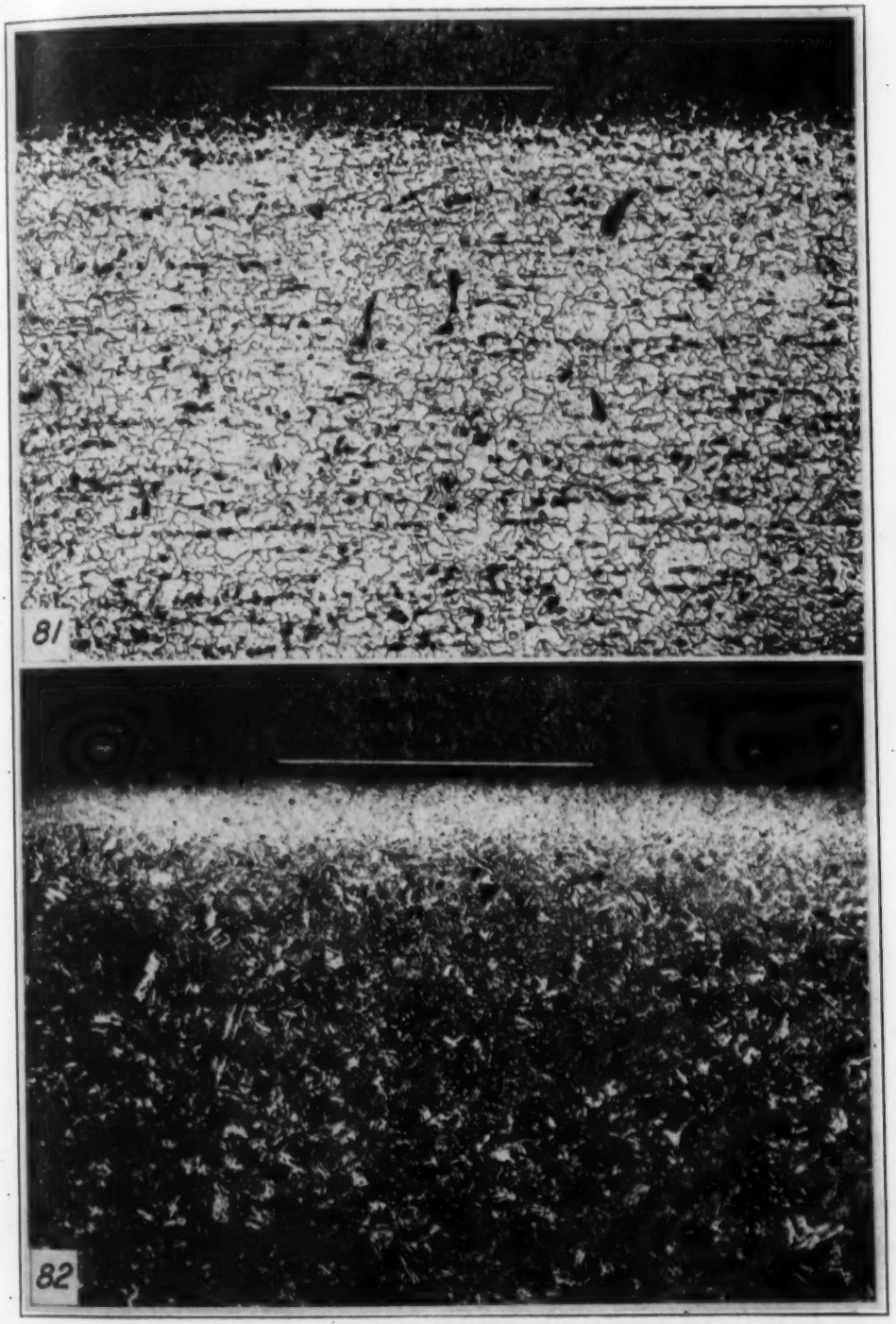

Fig. 81—Low Carbon Steel Cyanided at 1550 degrees Fahr., and Cooled Slowly. × 100. Etched in Alcoholic Nitric Acid.

Fig. 82—Low Carbon Steel Cyanided at 1550 degrees Fahr. and Quenched in Water. × 100. Etched in Alcoholic Nitric Acid.

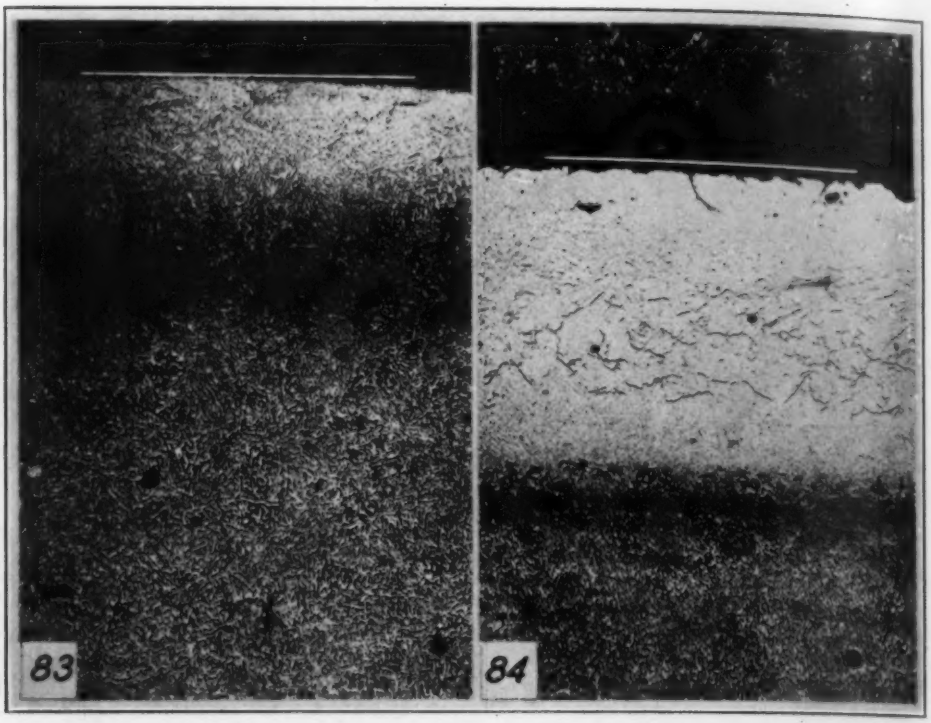

Fig. 83—Nitrided Steel, As Received, Showing Structure of Case and Transition Zone. × 100. Etched in Alcoholic Nitric Acid.
Fig. 84—Same Steel as Fig. 83, Annealed, Showing Distinct Case. × 100. Etched in Alcoholic Nitric Acid.

after this operation is complete. The case imparted by this treatment is so hard that it will scratch glass with ease. It is claimed that the corrosion resistance of the nitrided part is equal in many cases to that of stainless steel. Some growth occurs in nitriding; an average of approximately 0.001 inch.

The structure of a nitrided steel is shown in Figs. 83 and 84. Fig. 83 shows the case and the transition zone of the material as received. Fig. 84 shows the same specimen after annealing for two hours at 1750 degrees Fahr. The case depth on this particular specimen was approximately 0.005 inches and the transition zone a little more than this (Fig. 83). It will be noted that annealing has served to equalize the structure in the case and transition zone and has given it the appearance of a distinct layer (Fig. 84).

Abnormal and Normal Carburizing Steel

It has long been known that some low carbon steels when carburized and heat treated do not give a uniformly hard case. The

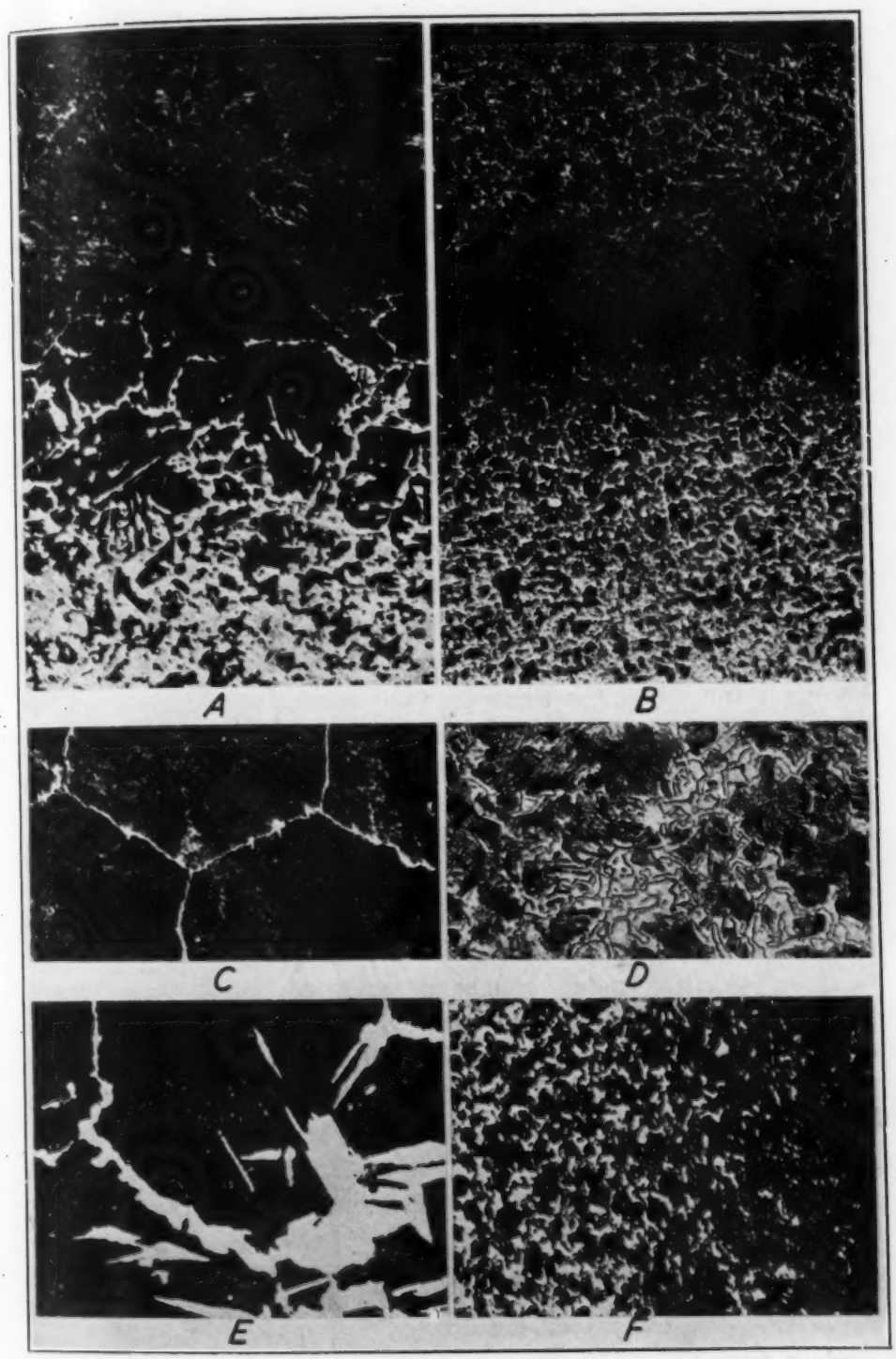

Fig. 85—Photomicrographs of Normal and Abnormal Steels (Ehn). × 100.

cause for the soft spots resulting from heat treatment of these steels was not known until Ehn, McQuaid and Ehn, Epstein, and Rawdon and others[61] investigated this phenomenon and helped us to understand it better. Ehn advanced the opinion that it was due to steel which contained oxides, or which was imperfectly deoxidized in making. Others have disputed this contention with the result that in the last five years the literature on this phase of carburizing has grown to voluminous proportions[62]. The work on these steels has accordingly received so much attention that we will only summarize it briefly.

Ehn has classified the low carbon carburizing steels as abnormal and normal; the former referring to steels which do not harden uniformly; the latter referring to steels which harden after carburizing with a case that is free from soft spots. There is nothing in the chemical composition or physical characteristics of the steel which gives any clue to the degree of "normality" or "abnormality". The difference however, is clearly revealed by the structure after carburizing.

According to Ehn, if a low carbon steel is carburized at 1725 degrees Fahr. so that a thick case is obtained and then examined after slow cooling, the metallographic structure will indicate how the steel will behave in hardening. Typical structures of normal and abnormal steels taken from one of Ehn's papers are shown in Fig. 85.[63] The normal steel is shown at the left, the abnormal steel at the right. According to this author the steel whose structure is shown in A, C, E, will give a uniform martensitic case in hardening but the abnormal steel B, D, F, will give a case having numerous soft troostitic spots when hardened.

The normal steel is characterized by a case containing a hypereutectoid zone made up of pearlite and free cementite existing as a network around the large pearlite grains. (C, Fig. 85). In the abnormal steel the grains are composed of pearlite, considerable free ferrite and small curved particles of cementite (D, Fig. 85) indicating that some of the pearlite has undergone complete divorce. The grains are not sharply defined as is the case in the normal steel. In the transition zone of the normal steel (E, Fig. 85) the

[61] See references to footnotes 56 and 62.

[62] See Epstein and Rawdon, TRANSACTIONS, American Society for Steel Treating, September, 1927, page 337. These authors give complete references.

[63] TRANSACTIONS, American Society for Steel Treating, Vol. 2, 1922, page 1181.

pearlite grains are large and angular; in the abnormal steel they are small and rounded (F, Fig. 85). The difference in structure between the abnormal and normal steels in the case, transition zone, and core is plainly shown in A and B of Fig. 85.

The micrographs shown in Fig. 85 are representative of two extreme cases which are occasionally encountered in commercial carburizing. There are of course many graduations in structure possible between the two sets shown in Fig. 85. Some mills place so much reliance upon the structure as indicative of the carburizing properties of the steel, that they have prepared charts of structures which they use as a standard for grading their carburizing steels.

From the large amount of work he did on carburizing steels, Ehn holds the theory that abnormality is due to dissolved oxides in the steel. He states that the extent to which deoxidation takes place in the melting furnace, has an important bearing upon the character of the hardened case; and that the results obtained in the carburizing operation constitute a check upon how thoroughly the steel was deoxidized in the furnace. If oxides are present in the steel due to improper deoxidation no subsequent treatment will change the abnormal carburizing properties.

Epstein and Rawdon have done much work on this subject and have summarized their experiments recently.[64] They found that the presence of a dissolved gas in the quenching medium (water) such as oxygen, nitrogen, and especially carbon dioxide was responsible for these soft spots in quenching. They say that abnormal steels however must be cooled more rapidly than normal steels and that when given a drastic quench no soft spots will be found. They found further that a normal steel could be made abnormal by the addition of aluminum to the molten metal in the ingot mold and that vanadium acted in the same manner.

It may be said that the structural differences between normal and abnormal steels are plainly evident in most cases and can be readily detected by microscopic examination, but as yet there is no generally accepted theory to explain the phenomenon.

[64] TRANSACTIONS, American Society for Steel Treating, September, 1927, page 337.

Recommended Practice Committee Releases*

NICKEL-CHROMIUM CAST IRON

By Dr. Paul D. Merica*

NICKEL-CHROMIUM cast iron like nickel cast iron†, is currently produced in a variety of compositions, suited to particular casting or foundry problems for which they were designed. The range is generally not over about 3.0 per cent nickel and 1.0 per cent chromium. Nickel and chromium are used together in gray iron primarily for the purpose of refining its structure, and of hardening and strengthening it without impairing its machinability.

With respect to their effect upon iron, chromium resembles nickel in some features. It refines the graphite structure of iron, hardens and strengthens it (Fig. 1), but in vivid contrast to nickel, chromium increases the chilling tendency of iron and promotes the formation of free carbide, and its hardening effect on iron is partly due to carbide formation.

Chromium acts, therefore, in an opposite manner both to silicon and to nickel in this respect, and neutralizes their chill-restraining effect. One part of chromium will approximately neutralize and balance one and one half parts of silicon or three parts of nickel. Chromium has a pronounced effect on the chilling tendency and therefore on the machinability of gray iron, and it must be used with caution if machinability is to be preserved.

Chromium also acts to build up combined carbon in iron (Fig. 1), and it is this feature which renders it useful in conjunction with nickel, for nickel does not exert its full beneficial effect upon iron except when the iron has pearlitic structure; viz., when the combined carbon is in the range 0.6 to 0.8 per cent. Hence, it is generally necessary when using nickel in iron to take some other step at the same time to secure high combined carbon, since nickel alone (at least below 1.50 per cent) will not normally build it up. It was shown in the data sheet on Nickel Cast Iron that this could be accomplished by lowering the silicon content. An equivalent step is the simultaneous addition of chromium with the nickel.

Nickel and chromium are added to iron in the proportion in which they mutually neutralize each other in respect to chill, the resulting alloy iron will have the same chilling tendency as the plain iron to which the alloys were added, and castings made from it will consequently be as readily machinable‡ as castings from the plain base iron. At the same time the refining, matrix hardening, and strengthening effects of both alloys will be

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†The data sheet on Nickel Cast Iron should also be read. Published in August, 1929, issue of the TRANSACTIONS, American Society for Steel Treating.

‡See discussion in Nickel Cast Iron data sheet on machinability.

***The releases from the Recommended Practice Committee as printed herewith will be included in the next edition of the A. S. S. T. HANDBOOK, which will be published about June 1, 1930.**

conserved and reflected in the structure and properties of the casting. Figs. 2 and 3 illustrate the effect of adding nickel and chromium to gray iron in what may be called a balanced ratio.

Fig. 2 shows that it is generally possible to secure about the same measure of improvement in the properties of castings (for equal machinability) either by adding nickel and chromium in balanced ratio (2½ to 1)

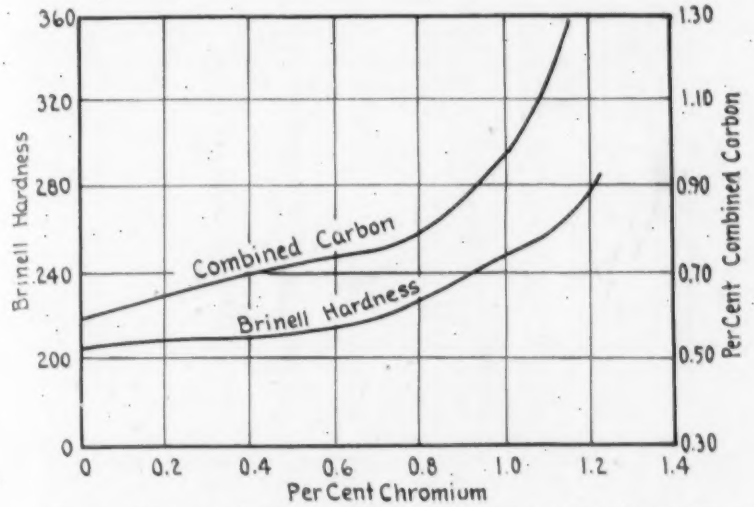

Fig. 1—Effect of Chromium on the Hardness and Combined Carbon of Gray Iron (Arbitration Bars.) (Trantin).

directly to the plain iron, or by changing the composition of plain iron base by lowering the silicon content and adding an equivalent quantity of nickel.

It is this method of using nickel and chromium, in balanced proportion, which usually gives optimum results in respect both to machinability and to mechanical properties. In addition, it is the simplest method of their use, since they may safely be added directly in these proportions to any plain base iron.

If this ratio is departed from, and in particular, if it is lowered and relatively more chromium used, then other changes must be made as well in the composition of the iron to balance the powerful effect of the excess chromium on chill and machinability. Normally, it is necessary to raise the silicon content by an equivalent amount. For heavy sections or when used in soft (high silicon) iron, this ratio may obviously be lowered to 1½ to 1, or even 1 to 1.

Uses of Nickel-chromium Iron—The industrial application of nickel and chromium in gray iron is best illustrated by the use of actual typical examples taken from current foundry practice. The current industrial applications of nickel-chromium cast iron are similar to those of nickel iron; viz., for applications requiring better structure, greater hardness, wear resistance and strength in readily machinable castings than can be obtained in plain iron.

Since equal results can generally be obtained, structurally and me-

chanically, by the use either of nickel alone (with simultaneous lowering of silicon or carbon) or of nickel and chromium, the question may be asked, what is preferable? Sometimes there is little choice economically between them. However, there are certain considerations that generally determine the choice.

First that of size and section of casting. In hardening and strengthen-

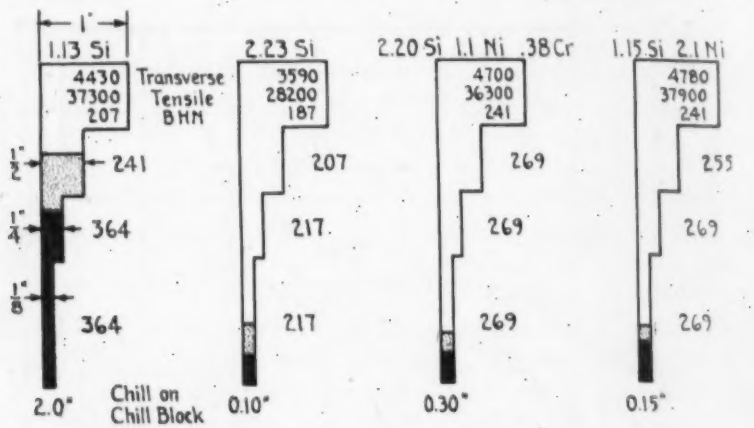

Fig. 2—Hardening Gray Iron by Nickel and Chromium in Balanced Ratio, and Comparison of Nickel-Chromium with Nickel Cast Iron. The Step Bar Test.

ing heavy sections (1 inch and over) it is usually more economical to use nickel and chromium than to use the larger amount of nickel which would be necessary in order to secure the same results. In lighter sections, in cases where machinability is a consideration, it is generally preferable to avoid the use of chromium.

When soundness of structure is desired, such as pressure castings, it is distinctly desirable to use a lower silicon content in order to avoid or to minimize structure difficulties such as porosity and internal shrinkage, and in such cases, of course, nickel alone should be used.

Finally, the use of nickel and chromium is often the more convenient, since it is easier and creates less disturbance in the foundry merely to add nickel and chromium to the regular iron normally used for any given casting, than to change the cupola mix and iron composition (in order to lower silicon content) and use nickel alone. Nickel and chromium are frequently cheaper as will be seen from Fig. 2, since 1.0 per cent of nickel in addition to the equivalent chromium is roughly equal in hardening and strengthening power to about 2.0 per cent of nickel alone.

The usual amounts of nickel and chromium added to gray iron to harden and strengthen vary within the following ranges:

	Nickel Per Cent	Chromium Per Cent
Small addition	0.05–0.15	0.10–0.25
Medium addition	0.75–1.50	0.25–0.50
Maximum addition	2.00–3.00	0.50–1.00

Hardness and Wear Resistance in Machinable Castings—This application

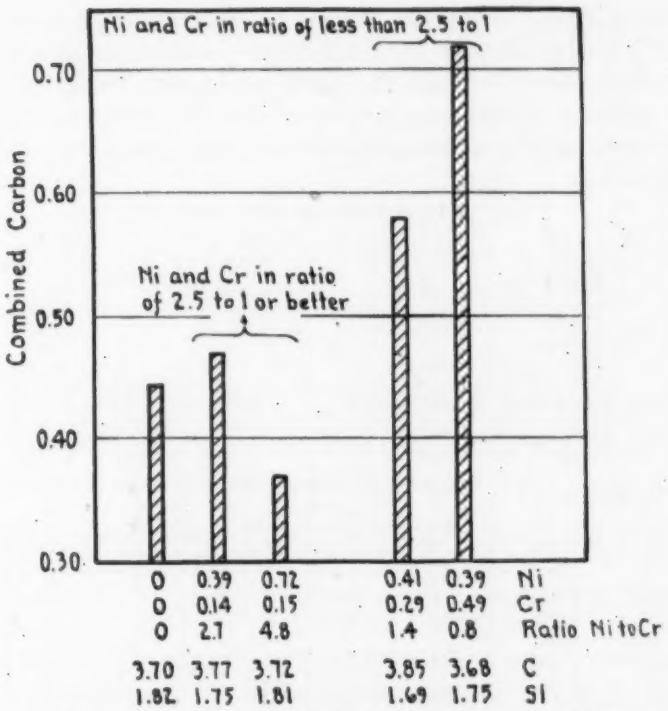

Fig. 3—The effect of Nickel and Chromium in different Proportions on the Combined Carbon Content of Gray Iron (Piwowarsky).

is a common one for nickel and chromium just as it is for nickel alone. The automobile cylinder block is one of the best illustrations.

1. *Automobile Cylinder Block*—Plain iron blocks (3⅝-inch bore) gave difficulty with excessive cylinder wear and with wear and pounding on the valve seats, causing cracking. By adding nickel and chromium in balanced ratio, the Brinell hardness on the bore was raised from 150 to 160 to 190 to 200; cylinder and valve seat wear were reduced and valve seat cracking eliminated. The machinability of the alloy cylinders was equal in all respects to that of plain iron.

COMPOSITION OF CYLINDER BLOCKS

	Alloy Iron Per Cent	Plain Iron Per Cent
Nickel	1.00–1.25	.....
Chromium	0.40–0.45	.....
Silicon	2.30–2.50	2.30–2.50
Carbon	3.20–3.40	3.20–3.40

A cheaper alloy mixture than the preceding one is used by another manufacturer who is obliged to meet a specification of 180 Brinell in his 3-inch bore cylinder blocks. The composition used is as follows:

	Per Cent
Nickel	0.75
Chromium	0.25
Silicon	2.15
Carbon	3.40

2. *Cams*—Cast iron cams for a special production machine were made

of plain iron, giving about 170 Brinell on the cam face. They gave inadequate wear resistance, not over four months service, and were replaced by nickel-chromium iron cams. These showed about 240 Brinell on the face, and have given over two years service. At the same time the alloy iron cams were more readily machined than the plain iron ones, which were hard on the edges.

COMPOSITION OF CAMS

	Per Cent Alloy Iron	Per Cent Plain Iron
Nickel	3.00	....
Chromium	0.90	....
Silicon	1.40	1.50
Carbon	3.30	3.30
Steel used in charge	35	....

Uniform Hardness in Castings—The combined carbon content of machinable iron castings may be held near the eutectoid amount (0.6 to 0.8 per

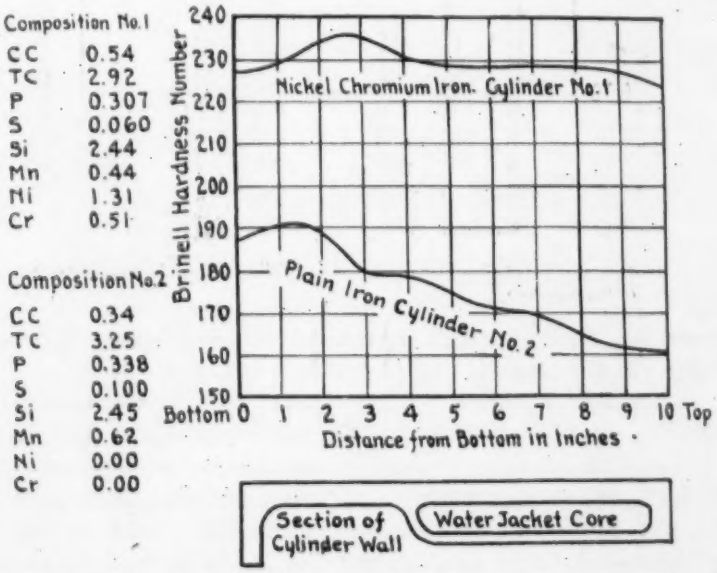

Fig. 4—Bore Hardness of an Automobile Truck Cylinder in Plain and in Nickel-Chromium Iron (Day).

cent) with resulting pearlitic structure, either by using nickel in low silicon iron or nickel-chromium iron. Castings with uniform combined carbon and pearlitic structure throughout, also show more uniform hardness in their different sections. This is generally a very desirable characteristic.

3. Automobile Truck Cylinder Block—Hardness surveys were made by one manufacturer along the bore of cylinder blocks (5-inch bore), cast both in plain iron and in nickel-chromium iron. The values are plotted in Fig. 4 and show both the greater hardness of the alloy iron block and its greater uniformity along the bore, opposite the cored sections, where cooling in the mold is retarded.

Fine Grain in Heavy Sections—If fine grain is sought in heavy sections, it is often preferable and economical to use nickel and chromium rather than nickel alone.

1. Grinding Machine Beds—These beds with a section of ¾ to 3 inches, cast in plain iron, were often too open in structure, and sometimes showed porosity and internal shrinkage at the points where T-slots had to be machined. The addition of the nickel and chromium secured finer grain and, consequently, better machine finish and eliminated the internal porosity.

COMPOSITION OF MACHINE BEDS

	Alloy Iron Per Cent	Plain Iron Per Cent
Nickel	0.75	....
Chromium	0.50	....
Silicon	1.90	1.90
Carbon	3.40	3.40

Use of Nickel and Chromium in Small Proportions—Nickel and chromium even in small amounts appear to produce a definite and appreciable effect upon the structure and properties of iron. There is today a substantial use of these alloys in the following amounts:

	Per Cent
Nickel	0.05–0.15
Chromium	0.10–0.25

The purpose of these small amounts is to secure grain refinement together with moderate increase of hardness and strength. Generally, they are added in the cupola as Mayari pig iron, the charge carrying from 5.0 to 15.0 per cent of Mayari pig. The analysis of this iron is given below:

COMPOSITION OF MAYARI PIG IRON

	Per Cent
Nickel	0.80–1.25
Chromium	1.60–2.50
Silicon	usual ranges for pig iron
Carbon	3.80–4.50 (depending on grade)
Manganese	0.60–1.00 (standard)
Phosphorus	0.10 max.
Sulphur	0.05 max.
Vanadium	0.05–0.08
Titanium	0.10–0.20

Production of Nickel-chromium Cast Iron—Nickel-chromium iron of usual compositions can be readily produced in regular iron foundry equipment and without any modifications of practice except those incident to the introduction of the necessary alloy content into the iron. The melting temperature, contraction, and other casting characteristics of such iron are the same as those of plain gray iron of equivalent silicon and carbon content.

The alloys themselves are introduced into iron both in the furnace or in the ladle.

For ladle additions a variety of materials are available including:

1. Pure (99 per cent) nickel shot
2. Low melting point nickel shot ("F" shot), containing 92 per cent nickel and 6 per cent silicon
3. Ferrochromium ground to 12-20 mesh
4. Nickel-chromium alloys of different compositions and having different trade names, but carrying generally 12 to 25 per cent chromium and 50 to 60 per cent nickel.

One may use either nickel shot and ferrochromium separately, or an alloy of the two in shot form which has the correct ratio of nickel to chromium.

For cupola additions, particularly of small amounts of nickel and chromium, Mayari pig iron is generally used. In melting this iron in the cupola there may be a loss of from 10 to 25 per cent of the chromium contained, but the nickel content is practically entirely recovered. It may be noted that the nickel and chromium do not occur in Mayari iron in balanced ratio. This may be corrected when using it by adding at the same time, either in cupola or ladle, an amount of nickel adequate to restore this ratio (3 to 1) in the finished casting.

AUSTENITIC MANGANESE STEELS

By John Howe Hall*

Composition—The useful range of composition for austenitic manganese steels does not cover the entire area shown as "Austenitic" in Guillet's diagram. After quenching in water from a temperature of 1830 degrees Fahr. or slightly over, the steel will consist entirely of austenite only if the ratio of carbon content to manganese content lies between the values $C = 1.075 + \frac{0.1\ Mn}{3}$ and $C = 1.075 - 0.04\ Mn$.[1] In practice the composition of austenitic manganese steels lies within the following limits:

	C	Mn	Si	S	P
Per Cent	1.00 to 1.40	10.00 to 14.00	0.30 to 1.00	Max. 0.05	Max. 0.10

Manufacture—The steel is made either by mixing molten ferromanganese and molten low carbon steel in a ladle, or by adding suitable amounts of ferromanganese to a low carbon steel bath in the basic electric furnace. The bessemer convertor or the open-hearth furnace may be used to melt the low carbon steel to mix with the ferromanganese in the ladle. The ferromanganese may be melted in either the crucible, the cupola, or a small electric furnace. The cupola is the melting medium commonly used.

When making manganese steel in the electric furnace, more or less manganese steel scrap is generally incorporated in the charge. A basic lining has to be used, as the slags contain considerable amount of MnO, which would severely corrode an acid lining.

The carbon content of standard 80 per cent ferromanganese is such that, when the proper amount of manganese is added to the steel, the resultant carbon will be from 1 to 1.40 per cent. If the carbon is below 1 per cent, the steel is less resistant to wear. Carbon above 1.40 per cent is undesirable, as it increases the tendency of the steel to crack in heat treatment.

Ferromanganese ordinarily carries enough silicon to give the resultant steel at least 0.30 per cent silicon. No appreciable effect on the physical properties can be found from variations in silicon between 0.30 and 1 per cent.

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[1]John Howe Hall, *Journal of Industrial and Engineering Chemistry*, Vol. 7, No. 2, page 94 1915.

The sulphur is usually so low as to be negligible, because the manganese forms MnS with any sulphur present in the steel, which floats to the surface and enters the slag.

The phosphorus content is dependent upon that of the ferromanganese used. It is generally between 0.06 and 0.09 per cent. Up to 0.1 per cent phosphorus may be present in the steel without ascertainable harmful effect.

Heat Treatment—The heat treatment consists in heating the steel to between 1830 and 1940 degrees Fahr., and quenching it in cold water. This treatment produces a uniform austenitic structure. When the carbon exceeds 1.40 to 1.50 per cent, free cementite will be found in amounts which increase in proportion to the carbon content and which will decrease the toughness of the steel. If the heat treated steel should be reheated for a long time at 660 degrees Fahr. or for a shorter time at or above 750 degrees Fahr., it becomes brittle. This makes it impossible to reheat the steel for the removal of quenching stresses. As a result of the drastic quenching to which manganese steel is subjected, these stresses are of considerable magnitude even in parts of comparatively simple design. The design of manganese steel articles has to be kept within such limits that the stresses do not become excessive.

Properties of Austenitic Manganese Steel—In the rolled or hammered condition the properties of heat treated austenitic, high manganese steel will usually come within the following limits:

Tensile Strength Lbs. per Sq. In.	Limit of Prop.[1] Lbs. per Sq. In.	Elongation Per Cent in 2 In.	Reduction of Area Per Cent	Brinell Hardness
130,000 to 160,000	40,000 to 60,000	60 to 70	40 to 60	230

In the cast condition, the properties of the heat treated steel are as follows:

Tensile Strength Lbs. per Sq. In.	Limit of Prop.[1] Lbs. per Sq. In.	Elongation Per Cent in 2 In.	Reduction of Area Per Cent	Brinell Hardness	Single Shear Lbs. per Sq. In.
75,000 to 110,000	40,000 to 50,000	15 to 35	15 to 35	180 to 220	84,000

Hardening Power of Austenitic Manganese Steels—The hardening power of high manganese steel under cold working is extraordinary. By pounding a sample of manganese steel with a hammer, its hardness is easily raised to nearly 500 Brinell.

Applications of Austenitic High Manganese Steel—High manganese steel, because of its toughness and strength, and its power of hardening on the surface under pressure and pounding, is unexcelled for applications where abrasion, combined with heavy pressure or blows, must be endured. Typical applications of cast high manganese steel are railway and trolley frogs, crossings and switches, rock crusher parts, steam shovel dippers and teeth, etc. In the rolled condition, its chief application is in rails. A small amount is used for light forgings that are subjected to heavy wear.

Cast Steels Containing 1 to 2 Per Cent Manganese—In the last twenty years a considerable tonnage of cast steel, containing from 1 to 2 per cent

[1]Limit of proportionality is given because no well marked yield point can be established.

Table I
Composition and Physical Properties of 1 to 2 Per Cent Manganese Steel Castings

Heat Treatment Degrees Fahr.	Tensile Strength Lbs. per Sq. In.	Yield Point Lbs. per Sq. In.	Elong. Per Cent in 2 In.	Red. of Area Per Cent	Charpy Foot Lbs.	Endurance Limit
1650[1] Annealed	75,000– 90,000	40,000–50,000	24–27	37–43	2.5–7.0	42,000
1650 Air[1] Tempered 1250	70,000– 90,000	38,000–50,000	25–31	41–50	8–12	42,000
1650[1] Water Tempered 1200	85,000–100,000	50,000–75,000	20–27	38–62	13–24	46,500
1525[2] Air Tempered 600–1000	100,000–110,000	45,000–60,000	22–27	45–56	22–32	43,000–45,000

[1]C, 0.20 to 0.30 Per Cent; Mn, 1.15 to 1.60 Per Cent.
[2]C, 0.35 Per Cent; Mn, 1.70 Per Cent.

manganese and from 0.20 to 0.40 per cent carbon, has been produced. These castings have practically always been given a heat treatment consisting of either normalizing (with or without a reheating) or of quenching and tempering, in order to secure the high strength, elastic limit, and shock resistance that these steels so readily exhibit. Typical compositions and physical properties of these castings are given in Table I.

These low manganese castings are being used for a wide range of applications where great strength and toughness are required, such as truck and tractor parts, locomotive castings, anchor chain, dredge and steam shovel parts, etc. The low cost of manganese compared to that of the other metals used to alloy with steel, and the remarkably high physical properties which manganese confers upon heat treated cast steel have resulted in a rapid increase, during the last few years, in the tonnage of these steels produced.

Some of the other alloying elements, such as nickel, chromium, vanadium, and molybdenum, are often used in combination with a manganese content of about 1.50 per cent. This is generally done in a bona fide effort to produce a steel better than can be made with either the manganese or the other alloy alone, and some of these steels show a remarkably high combination of strength and toughness.

Cast steels containing from 2 to 5 per cent manganese have been but little used, and their possible advantages have not yet been ascertained. Certain of them appear to give promise of usefulness in special applications. The steels in the martensitic range, as shown by Guillet's diagram, are so brittle as to be of little or no interest to the engineer.

GLOSSARY OF TERMS USED IN X-RAY METALLOGRAPHY

By Dr. L. W. McKeehan*

This glossary is primarily intended for those who, while not themselves conducting experiments or tests in which X-rays are used, have occasion to consult publications in this field. It may have secondary value to those who prepare such publications and who wish to use terms that are unambiguous. A part of the glossary has appeared in the *Proceedings of* the American Society for Testing Materials[1] with a report of its Committee on X-Ray Metallography. It is here revised and extended and is supplemented by a list of German terms with their English equivalents. English compound nouns have generally been hyphenated, although the hyphen tends to drop as the terms become more familiar.

A (abbreviation)—Ångström unit, 10^{-8} cm; also written Å.U., A.U., A.

absorber (for X-rays)—A sheet of matter placed between the source of X-radiation and the place where it is detected or measured. When the absorber contains elements so chosen that the intensity of X-rays with undesired wave-lengths is especially reduced, the absorber is usually called a filter.

absorption coefficient (for X-rays in a substance)—The rate of decrease, per unit distance traversed in a substance, of the natural logarithm of the intensity of a parallel beam; usually written μ.

absorption-limit—See limit.

amorphous—Without crystal structure, so that the X-ray diffraction-pattern is like that of a liquid.

angle—See glancing angle.

Angström unit—Å, 10^{-8} cm.

anisotropic—Having different properties in different directions.

anticathode (in X-ray tubes)—The part of the anode which receives most of the cathode-rays, and in which the target, if any, is mounted.

asterism (in X-ray diffraction-patterns)—The appearance of streaks or bands approximately along radii of the pattern.

axial ratio (in crystals)—In the tetragonal system and in the hexagonal division of the hexagonal system, the ratio of the parameter for the principal crystallographic axis of highest multiplicity to the parameter for either one of the other principal axes, usually written **C = (c/a)**; in less symmetrical systems the continued ratio of all three parameters, usually written **a:b:c.**

axis (crystal)—One of three non-co-planar intersecting lines, fixed with respect to a crystal, which meet any crystal plane at points whose distances from the intersection of the axes, in terms of three parameters

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Prepared for the Nonferrous Data Sheet Committee of the Institute of Metals Division of the A. I. M. E. and the Recommended Practice Committee of the A. S. S. T.

[1] *Proceedings,* American Society for Testing Materials, Vol. 26 (1), pages 582-598; 1926.

(**a**, **b**, and **c**), one for each axis, are in the ratios of small integers; the principal crystal axes are those about which the symmetry is the highest possible to the crystal considered.

axis of symmetry—A line in a crystal about which a rotation through $2\pi/\mathbf{N}$, where **N** is 2, 3, 4 or 6, with or without a translation parallel to the line and with or without a reflection in a plane perpendicular to the line, replaces every element (point, line, and plane) of the crystal by an equivalent element. The axis is said to be **N**-fold and is a rotation-axis if neither translation nor reflection is involved, is a screw-axis if any other than a primitive translation is involved, and is a rotary-reflection-axis (N is not equal to 3) if reflection is involved.

balanced filters (for X-rays)—A pair of filters adjusted to give the same absorption except in the range of wave-lengths lying between their characteristic absorption-limits. When used alternately the difference in effect, if any, is due to X-rays having wave-lengths in this range.

basal plane—In tetragonal and hexagonal crystals, a plane perpendicular to the **c**-axis.

beam (X-ray)—A nearly parallel group of X-rays from a common source.

body—See bulb.

body-centered (concerning space-lattices)—Having the equivalent lattice-points at the corners of the unit cell, and at its center; sometimes called centered, or space-centered.

Bragg equation (for X-ray reflection—The equation $\mathbf{n}\lambda = 2\mathbf{d}\sin\theta$; see also reflection.

Bragg method (for X-ray or crystal analysis)—Using monochromatic or polychromatic X-rays and a single crystal of large size rotated through a small angle about an axis lying in a crystal face.

bulb (in X-ray tubes)—The glass (or other pressure-tight) part; when of metal, more usually called the body.

calcite—Natural rhombohedral $CaCO_3$, the primary standard crystal used in X-ray spectrometry.

cassette (in X-ray spectrographs)—A box for holding a photographic film or plate in position to receive the X-ray diffraction-pattern.

cell—See unit cell.

centered (concerning space-lattices)—Body-centered.

channel (in X-ray spectrographs)—A collimating system consisting of a hole through a thick piece of metal (usually in two parts to permit cleaning).

chaotic—See orientation.

characteristic X-rays—Series of monochromatic X-rays which are emitted (in addition to heterochromatic X-radiation) by a particular element when exposed to cathode-rays (or X-rays) of sufficiently high energy.

close-packed (concerning atomic arrangement in crystals)—Having one of two possible arrangements, one cubic and one hexagonal, in which equal hard spheres can be made to occupy the least total volume, and, by extension, having any of the hexagonal arrangements derived from the

second of these by expansion or contraction of the hexagonal axis. See face-centered and hexagonal close-packed.

coefficient—See absorption coefficient, mass-absorption coefficient, mass-scattering coefficient.

collimate—To isolate a parallel, or nearly parallel, beam of rays, as by slits, pinholes, or a channel.

continuous spectrum—Heterochromatic X-rays.

Coolidge (concerning X-ray tubes)—Having a high vacuum and a hot-wire cathode.

covering-operation—A general name for translations, symmetry-operations, and their combinations in extended structures by which every element (point, line, and plane) of the structure is replaced by an equivalent element. Besides translations and symmetry-operations there are screw-rotations about screw-axes and glide-reflections in glide-reflection-planes.

critical (concerning voltage, wave-length or frequency)—Limiting; see limit.

cross-direction (in rolled metal)—The direction parallel to the axes of the rolls during rolling.

crystal (noun)—A coherent piece of matter all parts of which have the same anisotropic arrangement of atoms; in metals usually synonymous with grain and crystallite.

crystal (adjective)—Of, or pertaining to, crystals.

crystal analysis—The determination of crystal structure.

crystal unit—Unit of structure.

crystalline—Composed of crystals.

crystallogram—A photographic (or other permanent) record of an X-ray diffraction-pattern produced by a crystal.

cube-centered (concerning space-lattices)—Body-centered cubic.

cubic (concerning crystals)—Having non-parallel 3-fold axes of symmetry, with other symmetry-elements. Sometimes called isometric or regular. The typical cubic crystal has three equivalent axes mutually perpendicular and the common parameter is usually written **a** (or $\mathbf{a}_0$).

dashed (concerning X-ray diffraction-patterns from crystal aggregates)—Made up of separately distinguishable images of the source.

Debye-Scherrer method (for X-ray crystal analysis—Using a monochromatic (or polychromatic) X-ray beam defined by pinholes, an aggregate of small crystals oriented more or less completely at random and a photographic film bent into an almost complete cylinder with its axis perpendicular to the X-ray beam at the crystalline specimen; practically indistinguishable from the Hull method; sometimes called the powder method.

define (X-rays)—To limit in angle, as by slits or pinholes; to collimate.

deviation (X-ray)—The angle between the direction of incidence (produced through the substance) and the direction of diffraction; twice the glancing angle of incidence; usually written 2θ.

diagram (for X-ray diffraction-patterns)—A representation, either a photograph as taken, or a projection therefrom; e.g. the index-diagram.

diamond-cubic (concerning atomic arrangements)—Similar to the diamond

in having two face-centered cubic arrangements of atom-centers either of which is displaced with respect to the other by one-fourth of the diagonal of the unit cube.

diffraction (X-ray)—The deviation of an X-ray beam by scattering from atoms which have some regularity of arrangement or spacing.

diffraction-pattern (X-ray)—The totality of the traces, on a plane or other surface, of the beams diffracted by a crystal or by a crystalline aggregate.

discontinuity (in absorption)—The change in absorption coefficient at a limit.

doublet (in characteristic X-ray spectra)—A pair of lines from the same element which differ little in wave-length; e.g. the **K**α —doublet, **K**α_1 and **K**α_2.

end-centered (concerning orthorhombic space-lattices)—Having equivalent points at the corners of the unit cell and at the centers of the pair of opposite faces perpendicular to the c-axis; same as side-centered with a different choice of axes.

equivalent (concerning points, lines, planes, atoms, etc.)—Being interchangeable by the covering-operations appropriate to the structure.

excite (X-rays)—To cause to be emitted.

exposure (to X-rays)—The time-integral of the intensity; with X-ray tubes of the same kind and operated under the same conditions the exposure is proportional to the product of the electron current through the tube by the time of operation.

face (crystal)—A natural surface, or a cut surface parallel to a possible natural surface.

face-centered (concerning cubic space lattices)—Having equivalent points at the corners of the unit cell and at the centers of its six faces. A face-centered cubic space-lattice is characteristic of one of the close-packed arrangements of equal hard spheres.

family (of crystal planes)—The planes in any one crystal which have common indices.

fiber-axis—See fibering.

fiber-diagram—An X-ray diffraction-pattern, or a chart prepared therefrom, showing the existence of fibering or measuring its completeness.

fibering (in crystalline aggregates)—The state of a crystalline aggregate in which the preferred orientations are obtained by rotation about a line, the fiber-axis. If fibering is complete all azimuths about the fiber-axis are equally probable. If fibering is incomplete the preferred orientations may reduce to a small number and the notion of fibering loses its value. Besides simple fibering there may be helical fibering in which the fiber axis has all the orientations assumed by the tangent to a helix of constant pitch. In ring-fibering the pitch of the helix is zero.

filter (for X-rays)—A sheet of matter selectively absorbing secondary or other undesired X-rays. See also balanced filters.

fluorescent screen (for X-rays)—A sheet of matter (usually mounted on

paper or other non-absorbent material) which emits visible or actinic light when exposed to X-rays.

fluorescent X-rays—Characteristic X-rays excited by X-rays.

focus (in X-ray tubes)—The spot on the target where the cathode rays are concentrated and which is therefore the principal source of X-rays; its shape and size are controllable by design.

focusing (concerning methods of X-ray or crystal analysis)—Using such a shape and position of sample and position of source that the diffracted X-rays from many (or all) parts of the sample fall close together in the diffraction-pattern; such methods permit the use of wide beams and require relatively short exposures. See Bragg method and Seemann-Bohlin method.

form (for equivalent crystal planes or lines)—Having the same indices, except for sign or order; e. g. the planes (110), (101) in a cubic crystal are both of the form $\{110\}$; the planes (110), (101) in a tetragonal crystal are not of the same form. The lines [210], [120], [012] in a cubic crystal are of the form $<210>$.

frequency (X-ray)—Measured by the equation $Nu = \mathbf{c}/\lambda$, wherein **c** is the velocity of propagation of light (3×10^{10} cm. per sec.) and λ is the wave-length in centimeters.

frequency-factor (for crystal planes of a form)—The number of different families of planes having the same form.

general (concerning X-radiation)—Heterochromatic.

glancing angle—The angle between the incident X-ray beam and the crystal planes from which reflection takes place, however, these may be inclined to the bounding surface of the crystal, usually written θ.

glide-reflection-plane—See plane of symmetry.

gnomonic projection—A projection in which each plane of a crystal is represented by the point in which the perpendicular let fall upon it from a fixed point meets the plane of the projection.

goniometer—An instrument for measuring angles or for setting objects in known orientations. Spectrographs and spectrometers are goniometers of a special sort.

grating-constant (in crystals)—Interplanar distance.

grating-space (in crystals)—Interplanar distance.

halo (in X-ray diffraction patterns)—A diffuse circular band.

hard (concerning X-rays)—Having great penetrating power, short wave-length, high frequency.

hemihedral (concerning crystals)—Having but one half of the symmetry-elements possible to the crystal system in which the crystal belongs; having different properties in opposite directions, or on opposite faces, or lacking symmetrically opposite faces.

heterochromatic (concerning X-rays)—Having a continuous series of wave-lengths, as from a tube operated below the critical voltage for its target.

heterogeneous (concerning X-rays)—Heterochromatic.

hexagonal (concerning crystals)—Having parallel 6-fold rotation-axes of symmetry, or a single set of parallel 3-fold rotation axes of symmetry

with planes of symmetry perpendicular thereto, and with or without other symmetry-elements. The typical hexagonal crystal has two equal axes (**b** = **a**) inclined at the angle $2\pi/3$ and a third axis (**c**) perpendicular to their plane.

hexagonal close-packed (concerning atomic arrangements in crystals)—Having atoms at the corners of the hexagonal unit cells, which are right prisms with rhombic bases, and at the centers of those (isosceles) triangular prisms which are similarly located halves of the hexagonal unit cells. The two sets of atoms are not crystallographically equivalent. If the atoms are arranged like hard equal spheres in contact, $\mathbf{c} = 1.663\ (=2\sqrt{6/3})$.

holohedral (concerning crystals)—Having all the symmetry-elements possible to the crystal system in which the crystal belongs.

homogeneous (concerning matter)—Having the same properties in every small region containing many atoms (but not necessarily isotropic).

homogeneous (concerning X-rays)—Monochromatic.

Hull method (for X-ray crystal analysis)—Using a monochromatic (or polychromatic) X-ray beam defined by slits (or pin-holes), an aggregate of small crystals oriented more or less completely at random and a photographic plate or a photographic film (if the latter, bent around a cylinder with its axis perpendicular to the X-ray beam at the crystalline specimen); practically indistinguishable from the Debye-Scherrer method; sometimes called the powder method.

identity-period (along a crystal line)—A primitive translation.

image (in X-ray diffraction-patterns)—By analogy with optics, a recognizable copy of the source of X-rays or of any aperture defining the X-ray beam.

index-diagram—A chart based upon an X-ray diffraction-pattern and permitting the assignment of indices to the families of planes responsible for the intensity maxima in the pattern.

indices—See Miller indices, Miller-Bravais indices, line-indices.

intensifier (for X-rays)—A substance placed in, on, or under a photographic emulsion or a fluorescent screen, or used in photographic development, to make the effects of X-rays more conspicuous.

intensifying factor (for X-ray intensifiers)—The ratio between the exposure when no intensifier is used to the exposure, for the same effect, when the intensifier is used, all other conditions remaining unaltered.

intensifying screen (in X-ray spectrographs)—A separately mounted intensifier.

intensity (X-rays)—The flux of energy per unit of time and per unit of cross section perpendicular to the direction of propagation.

interplanar distance (in crystals)—The perpendicular distance between the nearest equivalent planes of a family; usually written d. The indices of the planes may be written as a subscript, e.g. d_{100}.

inversion—A symmetry operation by which each point of a structure is replaced by a point at the same distance from a fixed point (the inver-

sion-center) but in the opposite direction therefrom. See also symmetry-operation.

ionization method—Any method of X-ray or crystal analysis which depends upon measuring the electrical conductivity of a gas exposed to the diffracted X-rays; great accuracy in angular measurement is possible, but not easy.

isometric (concerning crystals)—Cubic.

isotropic—Having the same properties in every direction.

K—The letter used to designate the series of characteristic X-rays having, for each element, the shortest wave-lengths; Greek letters and Arabic subscripts are used to distinguish the lines of the **K**-series; e.g. copper $\mathbf{K}\alpha_1$, molybdenum $\mathbf{K}\beta$; **L, M,** etc., are used to designate characteristic groups of X-rays of successively greater wave-length, but these are rarely used in crystal analysis.

lattice—Space-lattice. Lattice-lines and lattice-planes are lines and planes so chosen as to pass through more than one lattice-point, and two lattice-points respectively.

Laue method (for crystal analysis)—Using heterochromatic X-rays, a small fixed crystal and a plane screen, usually a photographic plate; the Laue spot is the image (of a pinhole or of the small crystal itself) characteristic of the resulting diffraction-pattern.

layer-line (in revolving-crystal and oscillating-crystal methods)—A row of spots due to families of planes equally inclined to the axis of rotation or oscillation. Compare with side spectrum, zero spectrum.

limit (in voltage, wave-length or frequency of X-rays)—A value, characteristic of the particular chemical element in question, on the two sides of which excitation, absorption, photographic effect, or the like, have sharply different values.

line (crystal)—A possible edge of a crystal.

line (in X-ray diffraction-patterns)—A straight or slightly curved narrow region of maximal intensity.

line (X-ray)—A group of monochromatic X-rays, not necessarily collimated.

line-focus (in X-ray tubes)—A focus with one dimension reduced to such an extent that the focus approximates to a segment of a straight line on the target in the plane determined by the axis of the tube and the direction from the target to the irradiated object. (This secures the advantages of a point source of X-rays without extreme local heating).

line-indices—The smallest integers proportional to the coordinate-differences, in terms of the parameters (**a, b,** and **c**), between equivalent points lying on a crystal line; written, in general [HKL], in particular, e.g. [210]; in cubic crystals the line [pqr] is perpendicular to the plane (pqr).

mass-absorption coefficient (for X-rays in a substance)—The rate of decrease, per unit mass traversed, of the natural logarithm of the intensity of a parallel beam; usually written μ/ρ. It is often more convenient than the absorption-coefficient because its use does not require knowledge of the density ρ. See also mass-scattering coefficient.

mass-scattering coefficient (for X-rays in a substance)—The rate of decrease, per unit mass traversed, of the natural logarithm of the intensity of a parallel beam, due to scattering alone; usually written σ/ρ; the excess of the mass-absorption coefficient, μ/ρ, over σ/ρ is called the true mass-absorption coefficent, μ'/ρ.

Miller indices (for crystal planes)—The smallest integers proportional to the reciprocals of the intercepts, in terms of the parameters (**a**, **b**, and **c**), of the plane on the three crystal axes; written, in general, (hkl), in particular, e.g. (210); see also form.

Miller-Bravais indices (for crystal planes in the hexagonal division of the hexagonal system only)—The smallest integers proportional to the reciprocals of the intercepts, in terms of the parameters (**a**, **a**, **a**, and **c**), of the plane on the four axes; written in general (hjkl), in particular, e.g. (1120); the index for the hexagonal axis is always written last; $k = -(h + j)$ and may be replaced by a period, thus (1120) and (11.0) are the same. Any two of the three equivalent axes 120° apart in the basal plane together with the fourth axis are crystallographically sufficient, but the use of four axes makes it easier to recognize planes of the same form.

monochromatic (concerning X-rays)—Having only a single wavelength.

monoclinic (concerning crystals)—Having only parallel 2-fold axes of symmetry, or parallel planes of symmetry, or both of these with the axes perpendicular to the planes. The typical monoclinic crystal has three unequal axes, one, but not more than one, of which, is perpendicular to two others. The unique axis is usually taken as the **b**-axis.

multiplicity (for axes of symmetry)—The value of **N** if the axis is **N**-fold.

order (in X-ray reflection)—The integral value of **n** in the equation $n\lambda = 2d \sin \theta$.

orientation (crystal)—Arrangement in space of the axes of a crystal; every crystal must at every moment have a definite orientation, only aggregates, in space or in time, can possess chaotic orientation; if not chaotic some one or more orientations must be preferred.

orthohexagonal (concerning crystal axes)—A set of mutually perpendicular axes for hexagonal crystals. In terms of the more usual hexagonal parameters (**a**, **a**, **c**) the orthohexagonal parameters are $a\sqrt{3}$, **a**, **c**.

orthorhombic (concerning crystals)—Having only parallel 2-fold axes of symmetry, with planes of symmetry parallel to the axes or with additional 2-fold axes perpendicular thereto, or with both. The typical orthorhombic crystal has three unequal axes mutually perpendicular.

oscillating-crystal method (for X-ray or crystal analysis)—Using a single crystal rotating at constant speed, but alternately in both directions, through less than a complete rotation (usually much less).

parameter (in crystals)—The length of an edge of the unit cell, usually written **a**, **b**, or **c**; especially, in cubic crystals, the length of the edge of the unit cube, usually written **a** or a_o.

pattern—Diffraction-pattern.

pinhole—A small round hole used to define a beam of X-rays.

plane (crystal)—A possible face of a crystal.

plane of symmetry—A plane in a crystal in which a reflection, with or without a translation parallel to the plane, replaces every element (point, line, and plane) of the crystal by an equivalent element. The plane is a reflection-plane if no translation is involved, and is a glide-reflection-plane if translation is involved.

point-group—A limited group of points (from 1 to 48 in number) possessing the same symmetry-elements as one of the 32 possible classes of crystals.

pole-figure (for crystalline aggregates)—A stereoscopic projection showing the preferred orientations of the normals to planes of a given form.

polychromatic—Having several distinct wave-lengths, e.g. the characteristic X-rays from a single element.

powder method (for X-ray or crystal analysis)—Using a loose aggregate of small crystals with chaotic orientation; applied, early but somewhat illogically, to methods using solid metals composed of crystalline aggregates; see Debye-Scherrer method, Hull method.

preferred—See orientation.

primary (concerning X-rays)—Emitted directly from the anticathode in the X-ray tube.

primitive—See translation.

principal spectrum (in revolving-crystal and oscillating-crystal patterns)—Zero spectrum.

pseudocrystalline—Possessing regularities of structure which result in a diffraction-pattern unlike that of a liquid or an amorphous solid, although true crystals are not present, e.g., stretched rubber is pseudocrystalline.

radiography—The use of X-rays in studying the macrostructure of single objects or assemblies (internal boundaries, inclusions, variations in density or composition, etc.).

random (concerning orientation)—Chaotic.

rating (for X-ray tubes)—The product of the allowable current by the (peak) operating voltage.

ratio—See axial ratio.

reciprocal lattice (for a crystal)—A group of points so arranged about a center that the line joining each point to the center is perpendicular to a family of planes in the crystal, and its length is inversely proportional to their interplanar distance.

reflection (X-ray)—Diffraction considered as due to scattering by crystal planes as units, these being the reflecting planes; monochromatic X-rays are reflected only when $\mathbf{n}\lambda = 2\mathbf{d} \sin \theta$, where **n** is order, λ wave-length, **d**, interplanar distance, and θ, glancing angle of incidence upon the planes considered.

reflection-plane—See plane of symmetry.

regular (concerning crystals)—Cubic.

revolving-crystal method (for crystal analysis)—Using a small single crystal rotating uniformly through many complete rotations during the time of the exposure.

rhombohedral (concerning crystals)—Having parallel 6-fold rotatory-reflection-axes, or a single set of parallel 3-fold rotation-axes, in either case without planes of symmetry perpendicular thereto, and with or without other symmetry-elements. The typical rhombohedral crystal has three equal axes ($\mathbf{c} = \mathbf{a}, \mathbf{b} = \mathbf{a}$) mutually inclined at an angle α is not equal to $\pi/2$.

rock salt—Natural (cubic) NaCl, the secondary standard crystal used in X-ray spectrometry.

rolling-direction (in rolled metal)—The direction, in the plane of the sheet, perpendicular to the axes of the rolls during rolling.

rotation-axis—See axis of symmetry.

rotation-diagram—A chart used in assigning indices to families of planes giving spots in the diffraction-patterns obtained in revolving-crystal or oscillating-crystal methods for crystal analysis.

rotatory-reflection-axis—See axis of symmetry.

scattering (X-ray)—The re-emission of X-rays from irradiated matter, without change of wave-length (except as modified by the Compton effect, which is negligible in crystal analysis); it takes place in all directions with respect to the incident X-rays, but more intensely (or more often) in some directions than in others.

screen (in X-ray spectrographs)—A flat or curved surface on which a diffraction-pattern may be observed, e.g. a fluorescent screen; sometimes, but not so properly, a shield.

screw-axis—See axis of symmetry.

secondary (concerning X-rays)—Emitted elsewhere than from the anticathode.

secondary spectrum (in revolving-crystal and oscillating-crystal patterns)—Side spectrum.

Seemann-Bohlin method (for crystal analysis)—Using a monochromatic (or polychromatic) X-ray beam of wide angular aperture, an aggregate of small crystals oriented more or less completely at random and spread on a cylinder, an element of which also passes along the single slit defining the X-ray beam, and a photographic film bent to fit another segment of the same cylinder; a focusing method.

series (in X-ray spectra)—A group of characteristic X-rays having the same excitation-limit; distinguished as **K**-series, **L**-series, etc. See also **K**.

shield (in X-ray spectrographs)—A plate, block, or the like, which prevents X-rays (usually secondary) from reaching the measuring or detecting device; a complete absorber.

shutter (in X-ray spectrographs)—A removable shield.

side-centered (concerning orthorhombic space-lattices)—Having equivalent points at the corners of the unit cell, and at the centers of the pairs of opposite faces perpendicular to the **a**-axis and to the **b**-axis. Same as end-centered with a different choice of axes.

side spectrum (in revolving-crystal and oscillating-crystal patterns)—A row of spots due to planes equally inclined to the axis of rotation or oscillation, but not parallel thereto. Compare with layer-line, zero spectrum.

simple (concerning space-lattices)—Having equivalent points only at the corners of the unit cell.

slit—A narrow opening with parallel sides, used to define a beam.

slit-system—A series of slits used to define a beam and to shield against secondary X-rays.

slitless spectrograph—Wedge-spectrograph.

soft (concerning X-rays)—Having little penetrating power, long wave-length, low frequency.

source (X-ray)—See focus.

space-centered (concerning space-lattices)—Body-centered.

space-group—An infinitely extended group of points possessing the same symmetry-elements and the same translations as one of the 230 different arrangements theoretically possible for atoms in crystals. The great number of space-groups as compared with point-groups is due to the fact that a different location in space for the same symmetry-elements is possible in the space-group but not in the point-group.

space-lattice (crystals)—A system of equivalent points formed by the intersections of three sets of planes parallel to pairs of principal axes; the space-lattice may be thought of as formed by the corners of the unit cells. See translation-group.

spacing (between crystal planes)—Interplanar distance.

spectrograph (X-ray)—An instrument using an extended surface—a photographic plate or film, or a fluorescent screen—for receiving the X-ray diffraction-pattern.

spectrometer (X-ray)—An instrument using a movable measuring device for exploring the X-ray diffraction-pattern.

spectrum (X-ray)—A distribution of X-rays along a line in accordance with wave-length, or a group of X-rays so distributable. The set of layer-lines furnished by the revolving-crystal method is sometimes called the complete spectrum. See also side spectrum, zero spectrum.

stereographic projection—A projection in which each plane of a crystal is represented by the point in which a perpendicular let fall upon it from a fixed point meets a sphere centered at the fixed point, and these representative points on the sphere are then represented in turn by the points in which lines drawn to them from the pole of a great circle of the sphere meet the diametral plane through the great circle.

structure—The arrangement of parts; especially, in crystals, the shape and dimensions of the unit cell and the number, kinds and positions of the atoms within it.

symmetry—See axis of symmetry, inversion, plane of symmetry.

symmetry-element—A general name for axes of symmetry, planes of symmetry and centers of inversion.

symmetry-operation—A geometrical operation which interchanges equivalent elements (points, lines, and planes) of a rigid geometrical figure. The possible symmetry-operations are rotations about rotation-axes passing through the center of the figure and reflections in reflection-planes passing through the same point. A rotatory-reflection is a compound

operation in which the rotation-axis must be perpendicular to the reflection-plane. An inversion is equivalent to a 2-fold rotatory-reflection about any rotatory-reflection-axis.

system (crystal)—One of the 6 classes into which the 32 possible types of crystal and the 230 possible types of structure have been divided on the basis of symmetry. They are triclinic, monoclinic, orthorhombic, tetragonal, hexagonal (including rhombohedral and hexagonal divisions), and cubic.

target (in X-ray tubes)—The part of the anticathode, wholly or predominantly of a single metal, or coated with a substance to be analyzed, where the focus lies.

tetartohedral (concerning crystals)—Having but one fourth of the symmetry-elements possible to the crystal system in which the crystal belongs.

tetragonal (concerning crystals)—Having parallel 4-fold axes of symmetry but no 3-fold axes of symmetry. The typical tetragonal crystal has two equal axes (**b** = **a**) perpendicular to each other and to a third axis (**c**).

translation (in a crystal or space-group)—A displacement parallel to a crystal line. A primitive translation is the least translation, without accompanying rotation or reflection, which replaces every element (point, line, and plane) by an equivalent element. Suitable fractional parts of a primitive translation may be combined with rotation or reflection in screw-rotations and glide-reflections.

translation-group—An infinitely extended group of points possessing the same translations as one of the 14 possible space-lattices in crystals.

transmission method (for X-ray or crystal analysis)—Having the diffracted X-rays emergent from a surface which does not face the source.

triclinic (concerning crystals)—Having no symmetry-elements, or only inversion-centers. The typical triclinic crystal has three unequal axes no two of which are perpendicular.

uniform (concerning X-ray diffraction-patterns)—Not dashed.

unit cell (in crystals)—The least parallelopiped which possesses the full symmetry of the crystal, and repetition of which without change of orientation builds up a crystal of any size.

unit cube (in crystals)—The unit cell in cubic crystals.

unit of structure (in crystals)—The group of atoms included by the unit cell, especially if the arrangement of the group indicates chemical relations between its members.

wave-length (X-ray)—The value of λ in the equation, $\lambda = \frac{2\mathbf{d}\sin\theta}{\mathbf{n}}$; wherein **d** is the interplanar distance in a crystal which reflects the X-rays at the glancing angle θ in the **n**th order.

wedge-spectrograph—An X-ray spectrograph (due to Seemann) in which the beams of incident and diffracted X-rays are limited by a wedge brought into contact with a face of the crystal; also called slitless spectrograph.

white (concerning X-rays)—Heterochromatic.

X (abbreviation)—X-unit, 10^{-11} cm; also written X.U.

X-radiation—X-rays in general, especially when their direction of propagation is not emphasized.

X ray (adjective)—Of or pertaining to X-rays.

X-ray analysis—The measurement of X-ray wave-lengths and intensities.

X-ray tube—An assembly of cathode, anticathode, and bulb (or body) suitable for the production of X-rays.

X-rays—Light-rays, excited usually by the impact of cathode-rays on matter; which have wave-lengths, between about 10^{-8} cm. and 10^{-9} cm.; also written x-rays; same as Röntgen-rays.

zero spectrum (in revolving-crystal and oscillating-crystal patterns)—A row of spots due to planes parallel to the axis of rotation or oscillation. Sometimes called zero line. Compare with layerline, side spectrum.

zone-axis (in a crystal)—A line parallel to several crystal planes; the planes to which it is parallel form its zone.

German Terms with English Equivalents

This list contains principally those German terms likely to be mistranslated. Many of the short words here given will usually be found in combination. Such combinations are only included if their proper translations cannot be derived from the translations for their parts. It must be understood that the translations given are to be preferred only when the term is used in its technical sense. In non-technical uses other equivalents will often be better.

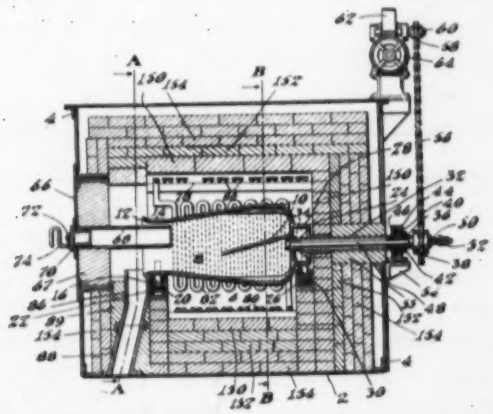
Ablenkungswinkel—deviation.
Absorptionssprung—absorption-discontinuity.
Anregung—excitation.
basisflächenzentriert—end-centered.
Basiszelle—unit cell.
Belichtung—exposure.
Beugung—diffraction.
Beugungsfigur—diffraction-pattern.
Bezifferung—indexing.
Bild—image.
Blende—shield.
Bremsstrahlung—heterochromatic X-radiation.
Brennfleck—focus.
Deckoperation—covering-operation.
dichteste Kugelpackung—close-packing of spheres.
Drehachse—rotation-axis.
Drehkristall—revolving-crystal.
Drehspiegelung—rotatory-reflection.
Eigenstrahlung—characteristic X-rays.
Elementarzelle—unit cell.
Erregung—excitation.
Faser—fiber.
Faserstruktur—fibering.
Fläche—face.
Gitter—lattice.
Gleitspiegelung—glide, reflection.
Häufigkeitsfaktor—frequency-factor.
Hauptspektrum—principal spectrum.
Lagerung—orientation.
Leuchtschirm—fluorescent-screen.
Loch—pinhole.
Nebenspektrum—side-spectrum.
Netzebene—lattice-plane.
Ordnung—order.
Punktgruppe—point-group.
Quelle—source.
Querrichtung—cross-direction.
Raumgruppe—space-group.
regellos—chaotic.
rhombisch—orthorhombic.
Röntgenröhre—X-ray tube.
Röntgenstrahlen—X-rays.
Röntgenstrahlung—X-radiation.
Schichtlinie—layer-line.
Schneide—wedge.
Schraubenachse—screw-axis.
Schraubung—screw-rotation.
Spalt—slit.
Spiegelebene—reflection-plane.
Spiralfaserstruktur—helical fibering.
Symmetriezentrum—inversion-center.
Walzrichtung—rolling-direction.
Würfel—cube.
Zähligkeit—multiplicity.
Zerstreuung—scattering.

Reviews of Recent Patents

By NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City—Member of A. S. S. T.

1,715,317, May 28, 1929, Heat-Treating Apparatus, Albert Vuilleumier, of Bristol, Connecticut, Assignor to The New Departure Manufacturing Company, of Bristol, Connecticut, a corporation of Connecticut.

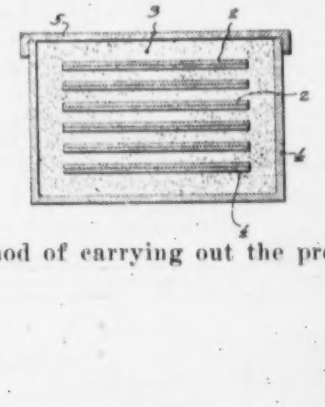
The heat-treating apparatus described in this patent consists of a furnace 2 having the usual metallic outer walls and insulating lining bricks



150-154. Inside the furnace is a rotating tumbling barrel 8 caused to rotate from the motor 64 through the drive chain 56 and rotating shaft 48. The barrel 8 is heated by suitable electric elements 76, 78, 80 and 82. The shape of the barrel 8 is such as to retain articles, such as steel balls undergoing heat treatment therein, by gravity. The balls may be charged into the furnace through the charging tube 68 and may be discharged through the discharge chute 88 into a suitable quenching tank upon tilting of the furnace.

1,716,191, June 4, 1929, Method of Treating Metallic Bodies on One Surface, Nathan H. Schermer and Charles G. Heilman, of Highland Park, Michigan.

The patent describes a method of case hardening one surface of a piece of metal while the other surface remains substantially at its original con-



dition. The typical method of carrying out the process is shown in Figure

3 in which sheets 2 are packed back to back in a suitable carburizing compound 3 in a carburizing box 4. When heated, the outer surfaces of the sheets 2 are penetrated by the carburizing compound to give a hardened case, while the surfaces of the sheets 2, which contact with each other, are not hardened. The particular use for sheets of this kind is in the making of brake drums in which the inner portion can be substantially of the original character of the sheet and the outer portion case hardened to withstand wear.

1,716,943, June 11, 1929, Aluminum-Beryllium Alloy and Method of Treatment, Robert S. Archer and William L. Fink, of Cleveland, Ohio, Assignors to Aluminum Company of America, of Pittsburgh, Pennsylvania, a corporation of Pennsylvania.

This patent describes an aluminum-beryllium alloy containing 0.025 to 1 per cent of beryllium and the method of heat-treating the same comprises heating the alloy to a temperature slightly below the melting point of the most fusible constituent to cause substantial solution of the undissolved beryllium compound, thereafter quenching the alloy from this temperature and subsequently aging at a temperature not higher than 200 degrees Cent. The beryllium alloy is of light weight and with the particular heat-treatment has higher physical properties than previously known aluminum-beryllium alloys.

1,717,153, June 11, 1929, Method of Desulphurizing Steel, Charles T. Hennig, of Cleveland, Ohio.

This patent describes a method of desulphurizing steel manufactured in a basic open-hearth furnace which comprises mixing soda into the molten iron forming a part of the open-hearth charge causing a violent agitation by the gases given off by the soda, and forming a soda containing a slag of higher fluidity than the ordinary basic slag. The iron thus treated is run into a bath of partially refined metal in the open-hearth furnace and the boiling is continued until the oxides and sulphides have been eliminated from the metal. Wood may be introduced into the open-hearth furnace to facilitate the reduction of the oxides and to increase the boiling action.

1,717,284, June 11, 1929, Fire-Resistant Alloy With High Electric Resistance, Hans Gustaf Albert von Kantzow, of Hallstahammar, Sweden.

This patent describes a new electric resistance and fire-resistant alloy consisting primarily of iron, 0.5 to 14 per cent of aluminum, and up to 30 per cent of chromium, to which 0.5 to 6 per cent of cobalt has been added. The addition of the cobalt raises the fire resistance several hundred per cent and the electrical resistance 20 per cent or more. The alloy is workable by rolling, drawing, etc.

1,718,331, June 25, 1929, Tank-Furnace-Heating Means. Robert P. Charleston, W. Va., assignor to The Libbey-Owens Sheet Glass Co., Toledo, Ohio.

1,718,364, June 25, 1929, Electrical Heating and Forging Machine. Frank P. Kobert, Springfield, Mass., assignor to Elektromatik Forging Machine Corporation, New York City.

THE ENGINEERING INDEX

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In the preparation of the Engineering Index by the staff of the American Society of Mechanical Engineers some 1700 domestic and foreign technical publications received by the Engineering Societies Library (New York) are regularly searched for articles giving the results of the world's most recent engineering and scientific research, thought, and experience. From this wealth of material the A. S. S. T. is supplied with this selective index to those articles which deal particularly with steel treating and related subjects.

AIRPLANE MATERIALS

TUBING. Curves Showing Column Strength of Steel and Duralumin Tubing, O. E. Ross. *Nat. Advisory Committee for Aeronautics—Tech. Notes,* no. 306, May 1929, 12 pp., 15 figs.

Set of column strength curves are given which are intended to simplify method of determining size of struts in airplane structure when load in member is known, and to simplify checking of strength of strut knowing size and length; weight of chrome-molybdenum streamline tubes can be determined since streamline tube has same cross-sectional area as its basic round tube.

TUBING. Strength of Tubing Under Combined Axial and Transverse Loading, L. B. Tuckerman, S. N. Petrenko and C. D. Johnson. *Nat. Advisory Committee for Aeronautics—Tech. Notes,* no. 307, June 1929, 17 pp., 13 figs. on supp. plates.

Results of study of strength of duralumin and chrome-molybdenum-steel round tubing only in combined transverse and axial loading; satisfactory semi-empirical method combines in single chart test results on three sizes of chrome-molybdenum tubing; same method applied to 1½-in. duralumin tubing; method makes it possible to raise design stresses in some ranges of diagrams by 100 per cent; modulus of rupture of tubes closely correlated tensile strength, but ratio undetermined.

AIRSHIP MANUFACTURE

METAL CONSTRUCTION. Stainless Steel Members in R-101, J. F. Hardecker. *Iron Age,* vol. 123, no. 26, June 27, 1929, pp. 1753-1758, 9 figs.

Metal construction of R-101 employing stainless steel in main frame is discussed; intersections between main frame and longitudinal girders; closed and open tube used for booms of girders and struts; methods employed by Boulton and Paul for working stainless steel; main longitudinal and frame longitudinal consist of stainless-steel booms, tubular duralumin struts, and swaged rod cross-bracing.

ALLOY STEEL

Broader Use for Alloy Steels, W. J. Priestley. *Iron Age,* vol. 12, no. 20, May 16, 1929, pp. 1339-1343.

Engineering progress demands stronger steels; aviation progress has been due to alloy steels; 1 to 2 per cent manganese steel widely used; rail steels of special manganese content; several new types of silicon; applications of chromium, nickel, molybdenum, stellite, aluminum-chromium, and of molybdenum steel for nitriding.

COPPER CONTENT. Steel Containing Copper is Highly Resistant to Atmospheric Corrosion. *Eng. and Min. Jl.,* vol. 127, no. 24, June 15, 1929, pp. 964-966, 2 figs.

Five main types of corrosion are discussed; although best results from use of copper-bearing steel have been obtained from its application to atmospheric corrosion, experiments are still in progress in effort to adapt it to other items of classification; tests by American Society for Testing Materials, started in 1915, are not yet completed as some of sheets have not yet failed. Reprint from Nat. Tube Co.'s National Bul., no. 11.

OXYGEN CONTENT. Influence of Oxygen on Structure and Properties of Different Structural Steels (Der Einfluss des Sauerstoffs auf das Gefuege und einige Eigenschaften verschiedener Baustaehle), P. Oberhoffer, H. Hochstein and W. Hessenbruch. *Archiv fuer das Eisenhuettenwesen (Duesseldorf),* vol 2, no. 11, May 1929, pp. 725-735 and (discussion) 735-738, 43 figs.

Comparison of oxygen-rich and oxygen-poor nickel, chromium-nickel, chromium-tungsten, tungsten, chromium, molybdenum, and vanadium steels; behavior with casting and forging; differences between primary and secondary structure; tendency to overheating; embrittlement with annealing.

ALLOY STEEL MANUFACTURE

Manufacture of Alloy Steels, H. B. Greensted. *Can. Machy. (Toronto),* vol. 40, no. 10, May 16, 1929, pp. 40-41, and 83-84.

Methods of manufacture of alloy steels; employed by Algoma Steel Corp., are described; preparation of charge; addition of silicon

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pig; addition of nickel for nickel steels; proper heating necessary; internal ruptures in nickel steel will not weld; uses of alloy steels. Paper presented before Am. Soc. Steel Treating.

ALLOY STEEL PROPERTIES

Welding Facts and Figures, D. Richardson and E. W. Birch. *Welding Jl. (Lond.)*, vol. 26, no. 307, Apr. 1929, pp. 102-104.

Magnet and non-magnet steel; classification and properties of wear-resisting steels; case-hardening steels, hardening process, and hardening mixtures; protective coatings against carburizing.

ALLOYS

ANTI-CORROSIVE. Non-Ferrous Acid-Resisting Alloys, B. E. Field. *Metallurgist (Supp. to Engineer)*, May 31, 1929, pp. 77-78.

Review of Technical Publication No. 191 of American Institute Mining and Metallurgical Engineers, dealing particularly with alloys resisting attack by hydrochloric acid under chemical-plant conditions; binary alloys of nickel and molybdenum; another nickel-base acid-resisting alloy which contains no molybdenum has been developed, containing silicon and aluminum.

EUTECTIC—STRUCTURE. Influence of Rate of Cooling on Structure of Eutectics (Ueber den Einfluss der Abkuehlungsgeschwindigkeit auf die Struktur des Eutecktikums), G. Tammann and A. A. Botschwar. *Zeit. fuer Anorganische und Allgemeine Chemie (Leipzig)*, vol. 178, nos. 1-3, Jan. 1929, pp. 325-328.

Very slow cooling of lead-bismuth eutectic alloy from just above to just below melting point, results in considerable segregation; similar results obtained by slowly cooling eutectic alloys of bismuth-tin, bismuth-cadmium, and lead-antimony; on over-heating eutectic iron-carbon alloy and cooling it slowly through melting point, large graphite needles separate.

HEAT RESISTING. Heat Resisting Alloys and Their Use in the Steel Plant, J. D. Corfield. *Iron and Steel Engr.*, vol. 6, no. 4, Apr. 1929, pp. 157-162 and (discussion) pp. 162-164, 7 figs.

Heat-resisting alloys are discussed with particular reference to application of these metals within steel industry; early history; nickel-chromium alloys; chrome-iron; alloys of future; physical properties; heat treatment general uses; steel plant uses.

MAGNETIC. Magnetic Alloys of Iron, Nickel, and Cobalt, G. W. Elmen. *Franklin Inst.—Jl.*, vol. 207, no. 5, May 1929, pp. 583-617, 23 figs.

Results of investigations at Bell Telephone Laboratories of magnetic properties of three ferromagnetic metals; particular applications made as result of discoveries; permalloys are used extensively in electrical communication circuits; their most spectacular use is for continuous loading of submarine telegraph cable; other alloys are still in commercial development stage, but it is believed that both perminvars and iron-cobalt alloys will take their places beside permalloy as important magnetic materials in electric communication.

ALUMINUM

X-RAY ANALYSIS. X-Ray Analysis of Aluminum at High Temperatures (Roentgenographische Untersuchung des Aluminiums bei hohen Temperaturen), A. J. Alichanow. *Zeit. fuer Metallkunde (Berlin)*, vol. 21, no. 4, Apr. 1929, p. 127.

Aluminum was analyzed in order to ascertain whether allotropic transformation takes place at temperatures between 575 and 600 deg. cent.; it was shown that structure remains unchanged.

ALUMINUM ALLOY CASTINGS

CORROSION. Influence of Occluded Gases on Susceptibility of Aluminum-Copper Alloys to Hydrochloric-Acid Attack (Influence des gaz oclus sur l'attaquabilite à l'acide chlorihydrique d'alliages aluminum-cuivre), R. Cazaud and A. Petit. *Revue de Métallurgie (Paris)*, vol. 26, no. 5, May 1929, pp. 281-285, 4 figs.

Object of present study was to determine manner in which casting conditions and occluded gases affected action of hydrochloric acid on aluminum alloys employed in aircraft.

DEFECTS. Pinholes in Aluminum Alloy Castings, N. F. Budgen. *Metal Industry (Lond.)*, vol. 19, May 10, 1929, pp. 461-462.

Pinholes due to shrinkage at solidification, and to occluded gases liberated at solidifications; latter played far greater part than shrinkage in causing pinholes; rate of solidification affects pinholes; while pure aluminum and 4 per cent aluminum-copper alloy have no pinholes, 8 per cent copper-aluminum alloy has profuse pinholes under certain conditions of melting. Abstract of lecture before Co-ordinating Societies.

ALUMINUM ALLOYS

ALUMINUM ALLOYS. *Machy. (Lond.)*, vol. 34, no. 870, June 13, 1929, pp. 333-335.

Influence of alloying elements in some of chief commercial alloys; heat-treatment characteristics and applications are outlined; aluminum casting alloys; aluminum-silicon alloys; aluminum wrought alloys.

AIRCRAFT. Strength and Ductility are Affected by Thickness and Heat Treatment, A. J. Lyon. *Foundry*, vol. 57, no. 13, July 1, 1929, pp. 550-553, 5 figs.

Data is given of effect of thickness and heat treatment on strength and ductility of light aluminum-copper alloys for airplane and engine parts; standard gating methods used; thickness of section has more pronounced effect on both tensile strength and ductility of heat-treated alloy than when it is in cast condition.

AUTOMOTIVE. Aluminum for the Automotive Industry, Z. Jeffries. *Soc. Automotive Engrs. Jl.*, vol. 24, no. 6, June 1929, pp. 617-619 and (discussion) 619-620, 7 figs.

Outline is given of strength that can be expected from various cast and wrought aluminum alloys, with heat-treatment necessary to develop best strength; for intercrystalline embrittlement, which causes trouble with thin sheets of aluminum alloy used around salt water, remedy offered is thin coating of practically pure aluminum, which is free from attack and protects stronger alloy both mechanically and dielectrically; magnesium-base alloys.

CORROSION. Micrographic Study of Corrosion of Certain Light Alloys in Seawater (Etude micrographique de la corrosion de

quelques alliages legers par l'eau de mer), R. Cazaud. *Revue de Métallurgie (Paris)*, vol. 26, no. 5, May 1929, pp. 274-281, 21 figs.

Results of analysis of extra pure and commercial aluminum, aluminum-silicon alloys, aluminum-magnesium alloys, and duralumin.

CORROSION. Measurement of Hydrogen-Ion Concentration Applied to Study of Corrosion of Light Alloys in Seawater (La mésure des pH appliquée à Pétude de la corrosion par l'eau de mer des alliages legers), A. Petit. *Revue de Métallurgie (Paris)*, vol. 26, no. 5, May 1929, pp. 285-286.

Apparatus employed in study consists of potentiometer employing two Soerensen hydrogen electrodes; results are summarized.

FATIGUE. Fatigue Resistance of Some Aluminum Alloys, J. B. Johnson and T. T. Oberg. *Am. Soc. Testing Matls.—Preprint*, no. 43, for mtg. June 24-28, 1929, 5 pp., 1 fig.

Paper is presented as additional data on endurance properties of aluminum alloys; endurance or fatigue limit has been assumed on basis of 300,000,000 cycles; results indicate that 500,000,000 cycles are insufficient to determine endurance limit; with modern aircraft equipment propeller may be subjected to over one billion alternations of stress in year's service; results of this investigation have led to reduction in allowable stresses used in design of aircraft propellers.

LAUTAL. Critical Dispersion of Lautal (Zur Frage der kritischen Dispersion des Lautals), H. Bohner. *Zeit. fuer Metallkunde (Berlin)*, vol. 21, no. 5, May 1929, pp. 160-165, 8 figs.

Critical discussion of earlier works; strength and conductivity measurements were carried out to determine critical dispersion; important relations were shown to exist between tensile strength and electric conductivity in dependence upon hardening temperature and time; practical importance of these results is pointed out.

MACHINE PARTS. Aluminum-Alloy Parts in Machine Construction, G. S. Affleck. *Am. Mach.*, vol. 70, no. 26, June 27, 1929, pp. 1013-1014, 3 figs.

Some of advantages of aluminum alloys for machine parts are given and certain applications cited; maker of gear shapers uses aluminum-alloy castings for internal working parts of machine to cut down inertia; alloys have increasing use in machine tools as well as in other machines for light moving parts.

PROTECTIVE COATINGS. Effect of Protective Coatings on Aluminum Alloys (Ueber die Wirkung von Schutzanstrichen auf Aluminium-Legierungen), H. Roehrig. *Korrosion u. Metallschutz (Berlin)*, vol. 5, no. 4, Apr. 1929, pp. 85-88, 6 figs.

It is claimed that great caution is necessary in selecting protective coatings for aluminum and its alloys against corrosive action of sweet and salt water; good results are obtained with paints containing no metals and those containing aluminum-bronze powder.

WELDING. Methods of Joining Aluminum and Its Alloys, A. Eyles. *Metal Industry (N. Y.)*, vol. 27, no. 5, May 1929, pp. 218-219, 2 figs.

Sound and homogeneous welds are readily obtainable in aluminum and aluminum alloys by autogeneous methods; arc, resistance, and electro-percussive methods of electric welding applied to aluminum; fluxes, welding materials, preparation of metal, and execution of weld described.

X-RAY ANALYSIS. Methods of Radiometallographic Analysis of Fractures and Internal Changes in Light Alloys (Valeur des methodes d'examen radiometallographiques pour diceler les fissurations et altérations internes au sein du métal dans les alliages légers), J. Cournot and A. Roux. *Revue de Métallurgie (Paris)*, vol. 26, no. 5, May 1929, pp. 272-274, 5 figs.

Results of measurements made with anticathode Coolidge tube on metals of high resistance supplied by Service Technique et Industriel de l'Aéronautique.

ALUMINUM BRONZE

Aluminum Bronze Data. *Foundry*, vol. 57, no. 12 and 13, June 15 and July 1, 1929, Supp. Sheet nos. 769, 770, 771 and 772.

June 15: Founding of aluminum bronze is discussed; self-annealing is probably outstanding peculiarity to be guarded against; defects found in machining and their causes. July 1: Causes of previously mentioned defects and their remedies are discussed; fatigue of aluminum bronze; specifications for aluminum bronze; melting practice.

PROPERTIES. Aluminum Bronze Data. *Foundry*, vol. 57, nos. 9 and 10, May 1 and May 15, 1929, supp. plates no. 764, opposite p. 395, and nos. 765 and 766 opposite p. 435.

May 1: Properties of aluminum bronze are described; table of average values of aluminum bronze. May 15: Properties of 10 per cent alloy in the cast state; all alloys are highly resistant to acid attack and to oxidation at red heat; tables of mechanical properties of Cu-Al alloys and of effect of iron, nickel, and manganese additions are given. Abstract of publication of Brit. Aluminum Co.

ALUMINUM CORROSION

Methods of Testing to Determine Corrosion Resistance of Metals to Weathering and Seawater (Pruefverfahren zur Beurteilung der Korrosionsbestaendigkeit von Metallen gegen Witterung und Seewasser), E. Rackwitz and E. K. O. Schmidt. *Korrosion und Metallschutz (Berlin)*, vol. 5, no. 1, Jan. 1929, pp. 7-13, 11 figs.

Methods of testing aluminum and aluminum alloys are described, combining immersion in 3 per cent sodium-chloride solution with physical tests; methods give results which are in close agreement with those found in actual service tests in atmosphere and in seawater.

Decreased Attack on Aluminum in Alkali Solutions Due to Colloid Additions (Ueber die Verminderung der angreifenden Wirkung von alkalischen Loesungen auf Aluminium durch Kolliodzusaetze), H. Roehrig. *Korrosion und Metallschutz (Berlin)*, vol. , no. 2, Feb. 1929, pp. 41-43.

Colloids, such as glue, agar agar, starch, gum arabic or gelatin, when added to 10 per cent sodium-hydroxide and crystallized sodium-carbonate solutions, markedly decreased rate of solution of aluminum; protection is increased by increasing concentration of colloid; limited concentration is determined by viscosity of results of solution.

Tests on Corrosion of Aluminum and Commercial Aluminum Alloys (Versuche ueber Korrosion von Aluminium und verguetharen

Aluminium-Legierungen), W. Schwinning and H. Jahn. *Korrosion u. Metallschutz (Berlin)*, vol. 5, no. 3, Mar. 1929, pp. 49-56 and (discussion) 56-58, 14 figs.

Table is presented giving average values based on results of hydrochloric-acid test and oxidic sodium-chloride, and relative values of bending coefficients; contradictory results show rapid testing methods are only to very limited degree applicable for comparison of corrosion resistance of different light metals and alloys.

ALUMINUM RECRYSTALLIZATION

Recrystallization of Single Crystals of Aluminum (Rekristallisation von Aluminium-einkristallen), W. G. Burgers and J. C. M. Basart. *Zeit. fuer Physik (Berlin)*, vol. 54, no. 1, and 2, Mar. 21, 1929, pp. 74-91, 16 figs.

Small aluminum single crystals are deformed by rolling; crystal structure so produced is studied by Debye-Scherrer pictures; relative position of single crystal and application of deforming force determines resulting structure after rolling; heating for few seconds (600 deg.) produced definite system with preferred orientation.

ALUMINUM STRUCTURE

Transcrystallization of Aluminum (Ueber die Transkristallisation des Aluminums), E. Scheil. *Zeit. fuer Metallkunde (Berlin)*, vol. 21, no. 4, Apr. 1929, pp. 121-124, 6 figs.

Transcrystallization is explained as stalky formation of crystals; relation of this structure formation to casting conditions has been studied.

AUTOMOBILE PLANTS

HEAT TREATING DEPARTMENTS. Oakland Heat-Treating Facilities Among Most Modern in Industry, A. F. Denham. *Automotive Industries*, vol. 60, no. 21, May 25, 1929, pp. 796-798, 5 figs.

Description of heat-treating installations in recently revamped axle and transmission plant of Oakland Motor Car Co., Pontiac; main installation provides for all operations on gears from hardening furnace to final straightening and burnishing, with minimum labor.

AUTOMOBILE MANUFACTURE

HEAT TREATMENT. Universal Heat Treating Unit in Operation at Packard Plant. *Fuels and Furnaces*, vol. 7, no. 6, June 1929, pp. 895-898, 5 figs.

Three large furnaces with pushers and pullers interconnected with time controls form one continuous and automatic unit and can be adjusted for four operations in one, such as normalizing, heating for hardening, quenching and drawing.

CADMIUM PLATING

Details of Cadmium Plating, O. H. Loven. *Metal Industry (N. Y.)*, vol. 27, no. 5, May 1929, pp. 224-227, 1 fig.

Methods of cadmium plating and equipment employed are reviewed; general composition formulas; electrical control; cleaning operation; use of reverse current; plating time and barrel speed; testing plate; interpreting test results; maintaining solution; washing plated work; decorative value.

CASE HARDENING

CARBURIZING. The Constitution of Steel and Cast Iron, F. T. Sisco. *Am. Soc. Steel Treating—Trans.*, vol. 16, no. 1, July 1929, pp. 155-164, 2 figs.

Operation of carburizing is discussed; low-carbon steels are used for carburizing because they give hard case and soft ductile core; chemical reactions taking place when steel is carburized with solid cements; various compounds commonly used; carburizing temperatures and depth and chemical composition of case.

CYANIDE. Case-Hardening in Cyanide Baths, F. Rapatz. *Iron and Steel Industry (Lond.)*, vol. 11, no. 8, May 1929, pp. 241-242 and 251, 6 figs.

Results of tests of Durferrite; structures of cases produced at 850 and 950 deg. cent. at various depths from surface; practical considerations; most favorable cementation temperature is about 850 deg. cent.; cases produced are readily hardened and conform to requirements; in case of small mass-produced parts process appears economically sound.

DEPTH MEASUREMENT. A New Method of Measuring the Thickness of Hard Cases, E. G. Herbert and P. Whitaker. *Fuels and Furnaces*, vol. 7, no. 6, June 1929, pp. 923-926, 3 figs.

Development of means for applying differential method to measurement of case thickness which method takes into account three variables, case hardness, case thickness, and core hardness.

CAST IRON

ALLOY CLASSIFICATION. Classification of Gray Iron Alloys, J. W. Bolton. *Am. Soc. Testing Matls.—Preprint*, no. 35, for mtg. June 24-28, 1929, pp. 3-11, 4 figs.

Five factors influencing properties of gray-iron castings are enumerated; author advocates primary classification based upon chemical analysis, and secondary classification based upon cooling rate; in this latter connection he shows how mathematical formula can be applied to determine relative cooling rates of simple shapes.

HEAT TREATMENT. Heat Treatment of Cast Iron, F. B. Coyle. *Am. Soc. Testing Matls.—Preprint* no. 35, for mtg. June 24-28, 1929, pp. 71-74.

Discussion for convenience has been divided into three temperature ranges: (1) up to 800 deg. fahr. within which there is no change in structure or physical properties; (2) 800 deg. to critical range within which there is change in structure but no change in physical properties; (3) from critical range to melting point, within which both structure and physical properties change; author refers to extensive digest of literature of heat treatment of cast iron which is being prepared by Society's Committee A-3 on Cast Iron.

HIGH TEST. Cast Iron for High Stresses (Gusseisen fuer Hohe Beanspruchungen), B. Osann. *Maschinenbau (Berlin)*, vol. 8, no. 10, May 16, 1929, pp. 314-316, 2 figs.

Chilled and acid-resisting castings; special castings with high tensile strength especially for steam and gas engines, piston rings, automobile cylinders, etc.

HIGH TEST. How to Obtain High-Test Cast Iron (Wie erziele ich einwandfreies Gusseisen), B. Osann. *Maschinenbau (Berlin)*, vol. 8, no. 9, May 2, 1929, pp. 284-289, 11 figs.

Study is based on separation of graphite from pig iron; in order to control this and to obtain proper chemical composition, calculation is necessary for which four basic rules are given.

MEEHANITE. Characteristics of Meehanite Metal. *Am. Mach.*, vol. 70, no. 25, June 20, 1929, p. 987.

Description of Meehanite which is gray iron and is said to have two or three times strength and about twice stiffness of ordinary cast iron of similar casting and machining properties; it also has greater resistance to corrosion and may be heat-treated somewhat like steel; process of manufacture; typical uses.

PEARLITIC. Some Notes on Perlit Iron, R. T. Rolfe. *Iron and Steel Industry (Lond.)*, vol. 11, no. 9, June 1929, pp. 283-286, 6 figs.

Criticisms of Perlit process are discussed; example of tensile strength; consequence of equalization in cooling rate; microstructure of Perlit iron; Perlita process, not a composition.

CAST IRON ANNEALING

Annealing of Cast Iron, H. H Beeny. *Foundry Trade Jl. (Lond.)*, vol. 40, no. 661, Apr. 18, 1929, pp. 292-294.

Discussion of paper published in Mar. 28 and Apr. 4 issues of magazine. Annealing or heat treatment; analogy with malleable practice; graphite eutectic; white chilled iron structure; graphite eutectic as decomposition product; importance of manganese; malleable iron not envisaged.

CAST IRON CORROSION

Corrosion of Cast Iron, H. O. Forrest. *Am. Soc. Testing Matls.—Preprint*, no. 35, for mtg. June 24-28, 1929, pp. 61-70, 2 figs.

Factors affecting corrosion include not only characteristics of metal itself but to greater extent composition of corroding medium and type of protective coating employed; tests at Massachusetts Institute of Technology indicate only small differences in rates of corrosion of cast-iron pipe manufactured by different processes; primary requisites for good coatings are impermeability to water and freedom from pinholes; corrosion tests in soils point to fact that, in general, nature of soil rather than types of metal is factor which governs corrosion rate.

CAST IRON FATIGUE

The Fatigue Properties of Cast Iron, J. B. Kommers. *Am. Soc. Testing Matls.—Preprint*, no. 35, for mtg. June 24-28, 1929, pp. 35-43, 2 figs.

Results obtained in testing four lots of cast iron at University of Illinois and ten different cast irons at University of Wisconsin; in Illinois tests, fatigue strength of cast iron was markedly increased by oft-repeated stress below endurance limit; in Wisconsin tests, ratio of endurance limit to tensile strength showed average value of 0.49; formulas are given by which maximum unit stress for various ratios of minimum to maximum stress may be computed approximately.

CAST IRON PROPERTIES

Static Strength of Plain and Alloy Cast Iron, F. B. Coyle. *Am. Soc. Testing Matls.—Preprint*, no. 35, for mtg. June 24-28, 1929, pp. 23-29, 6 figs.

In author's opinion only tests for strength of cast iron which give absolute results are those for tension and compression; Maurer diagram showing relation between structure and composition of cast iron is given; extension of this diagram to show relation of composition and structure is presented, followed by series of diagrams showing extension of range of composition which will produce pearlitic structure and maximum strength.

Elasticity and Oscillating Strength of Cast Iron (Die Elastizitaet und die Schwingungsfestigkeit des Gusseisens), A. Thun and H. Ude. *Giesserei (Duesseldorf)*, vol. 16, no. 22, May 31, 1929, pp. 501-513, 18 figs.

Necessity of new materials-testing method is pointed out; stresses in cast-iron rods bent under static and rotating conditions; fatigue phenomena; surface sensitivity of cast iron.

Effect of Section and Various Compositions on Physical Properties of Cast Iron, R. S. MacPherran. *Am. Soc. Testing Matls.—Preprint*, no. 35 for mtg. June 24-28, 1929, pp. 12-18, 7 figs.

Study of effect of section on tensile strength and hardness of three types of cast iron: hard low-silicon gray iron, soft high-silicon gray iron, and high-test cast iron; whereas the two gray irons were appreciably harder at sides than at center, high-test iron here reported had practically equal Brinell hardness throughout; tensile strength of this iron decreases as thickness of bar increases.

Some Interrelationships in Grey Iron Metallurgy, J. W. Bolton. *Foundry Trade Jl. (Lond.)*, vol. 40, no. 669, June 13, 1929, pp. 449-454, 11 figs.

Two important problems before foundrymen; four factors which influence mechanical and physical properties of grey cast iron; relationship of volume to surface area significant factor; influence of manufacturing practice; relationship of test results; American trend in engineering and metallurgical thought. Paper presented before Int. Foundrymen's Congress.

Elastic Properties of Cast Iron, J. T. MacKenzie. *Am. Soc. Testing Matls.—Preprint*, no. 35, for mtg. June 24-28, 1929, pp. 30-34, 1 fig.

Cast iron is characterized by stress-strain relationship represented by curved plot from origin to breaking point; formulas for modulus of elasticity and for deflection or elongation of cast iron are given; results of some of author's work are shown presented in form of graphs; curves show striking correspondence between amount of "set" (plastic deformation) and amount of graphite; "ultimate" modulus of elasticity is index of resistance to plastic deformation.

Sponginess in Cast Iron, J. Butterworth. *Foundry Trade Jl. (Lond.)*, vol. 40, no. 665, May 16, 1929, pp. 362 and discussion, pp. 362-363.

Discussion of two defects in cast iron, namely pinhole resulting from occluded gases and dirt hole caused by oxidation of metal; sources of dirt; pinholes are formed by excess of gases dissolved in molten metal as they are liberated when iron is nearing solidification; effect of silicon content; dry-sand molds.

CAST IRON SPECIFICATIONS

Report of Committee A-3 on Cast Iron. *Am. Soc. Testing Matls.—Preprint*, no. 11, for mtg. June 24-28, 1929, 28 pp. 4 figs.

Recommendations affecting standards; subcommittee activities; report on correlation of

test bar and casting; report on heat treatment of cast iron; proposed tentative specifications for chilled-tread cast-iron wheels; and for gray-iron castings for valves, flanges, and pipe fittings.

CAST IRON TEST BARS

Correlation of Cast-Iron Test Bars and Castings, W. H. Rother and V. M. Mazurie. *Am. Soc. Testing Matls.—Preprint*, no. 35, for mtg. June 24-28, 1929, pp. 19-22.

Brief report of work undertaken by various investigators in attempting to correlate properties of cast-iron test bars with properties of casting; few really tangible facts have been established; investigators agree that more than one size of test bar is necessary where any account is to be taken of variation of strength with thickness; it is believed that much can be accomplished by casting test bars having same relative cooling rate as casting.

CAST IRON TESTING

Wear Testing of Cast Iron, A. L. Boegehold. *Am. Soc. Testing Matls.—Preprint*, no. 35, for mtg. June 24-28, 1929, pp. 50-60, 4 figs.

Review of work done on wear testing in general and particularly on cast iron; difficulties encountered in obtaining satisfactory results; regarding wear testing of cast iron for automobile-engine cylinder blocks, author describes method used by him; conclusions reached are: universal wear test is undesirable; laboratory wear tests in which service conditions are imitated give valuable data; wear testing with lubricants present is difficult; grit and lack of lubrication are largest factors in cylinder wear, etc.

Impact Testing of Cast Iron, H. Bornstein. *Am. Soc. Testing Matls.—Preprint*, no. 35, for mtg. June 24-28, 1929, pp. 44-49.

Impact of shock testing of cast iron has been studied by many investigators but no standard method has been developed; there is need for standard method of test; it is consensus of opinion that irons high in static strength are also high in impact value; in many cases, shock or impact test is greater value in predicting results in service than are static tests, particularly where casting is to be subjected to shock.

CHROMIUM PLATING

Fundamental Factors Involved in Chromium Plating, L. Weisberg and W. F. Greenwald. *Metal Cleaning and Finishing*, vol. 1, no. 1, May 1929, pp. 85-88 and 112.

Necessity of technical control in composition of solution is discussed; temperature of operation; current density; design of racks; relative cost of chromium plating and factors affecting cost.

A study of Chromium Plating, R. Schneidewind. *Metal Industry, (N. Y.)*, vol. 27, no. 2, Feb. 1929, pp. 74-75.

Excerpts from Bulletin giving account of research work done on chromium plating at University of Michigan during 1927 and 1928; non-technical account of chromium plating from chromic-acid baths; properties of chromium plate; process of electrodeposition of chromium.

CHROMIUM-NICKEL ALLOYS

Constitution of Nickel-Chromium Alloys, N. B. Pilling and T. E. Kihlgren. *Am. Soc. Steel Treating—Trans.*, vol. 15, no. 6, June 1929, pp. 1660-1661, 1 fig.

Recommended Practice Committee release is presented, including chart of nickel-chromium equilibrium.

CHROMIUM-NICKEL STEEL

TESTING. Tests of a Nickel Steel at High Temperatures, H. G. Tapsell and J. Remfry. *Engineering (Lond.)*, vol. 127, no. 3305, May 17, 1929, p. 606, 2 figs.

Results of experiments carried out at National Physical Laboratory for Engine Subcommittee of Aeronautical Research Committee on probable creep properties of high-nickel high-chromium steel at temperatures between 600 and 800 deg. cent.; intended for use in exhaust-turbine wheels for supercharger units. Abstract of special report, no. 15, of Department of Sci. and Indus. Research.

CHROMIUM STEEL

Chromium as an Alloying Element in Steel, M. A. Grossmann. *Am. Soc. Steel Treating—Trans.*, vol. 16, no. July 1929, pp. 165-170, 1 fig.

Recommended Practice Committee release. Notes on metallic chromium, chromium in steel, source of chromium; chromium automotive steels; chromium-nickel, chromium-vanadium, chromium-molybdenum, chromium-silico-manganese steels; ball bearing steels; air-hardening or self-hardening steels; high-speed and magnet steels.

COPPER

X-RAY ANALYSIS. An X-Ray Study of Copper which Showed Directional Properties on Cupping, A. Phillips and G. Edmunds. *Am. Soc. Testing Matls.—Preprint*, no. 48, for mtg. June 24-28, 1929, 10 pp., 4 figs.

Brief review of important literature dealing with orientation characteristic of copper in hard-rolled and annealed conditions; X-ray study, by monochromatic pinhole method, of annealed copper which showed directional properties on cupping is described; it is suggested that pronounced directional properties may be eliminated by limiting degree of cold working and avoiding excessively high annealing temperatures.

COPPER ALLOYS

PROPERTIES. Hardness Relationships and Physical Properties of Some Copper Alloys, C. H. Davis and E. L. Munson. *Am. Soc. Testing Matls.—Preprint*, no. 47, for mtg. June 24-28, 1929, 12 pp., 11 figs.

Hardness relationships of several commercial copper-zinc and copper-tin alloys, and three copper-nickel zinc alloys were studied; evidence of tensile tests and Brinell, Rockwell and scleroscope hardness values on annealing and rolling series are assembled in tables of data and plotted in 11 charts; hardness-tensile strength relationship varies progressively with chemical composition and is also dependent on previous mechanical and thermal treatment to which any single alloy has been subjected.

COPPER METALLOGRAPHY

Crystalline Changes in Copper Due to Annealing, F. C. Howard and E. T. Dunn. *Indus. and Engr. Chem.*, vol. 21, no. 6, June 1929, pp. 550-553, 8 figs.

Crystalline changes upon annealing rod of

cold-worked copper have been investigated, using strong etching reagent; laminated structure of etched crystals of copper which because of its regularity is probably due to some physical property has been photographed at relatively high magnification; two recommendations are made for further work.

DURALUMIN

ANNEALING. Dilatometric Investigations of Thermal Effects in Annealing of Duralumin and Its Constituents (Dilatometrische Untersuchungen der thermischen Effekte beim Anlassen von Duralumin und seinen Aufbaukomponenten), M. Haas and H. Hecker. *Zeit. fuer Metallkunde (Berlin)*, vol. 21, no. 5, May 1929, pp. 166-173, 30 figs.

Results of investigation are in agreement with practical experience.

CORROSION. Corrosion Embrittlement of Duralumin, The Effect of Corrosion Accompanied by Stress on the Tensile Properties of Sheet Duralumin, H. S. Rawdon. *Nat. Advisory Committee for Aeronautics—Tech. Note*, no. 305, May 1929, 26 pp., 9 figs. on supp. plate.

Tests show how and to what extent corrosion behavior of this material is affected by stress accompanying corrosive attack; effect of both static tension and repeated flexural stress is determined; corrosive attack with both stressed and unstressed specimens of aluminum-clad duralumin, is exceedingly slight even for long corrosion periods; in hot-water-quenched material intercrystalline type of attack is prominent. Bibliography.

CORROSION. The effect of Corrosion, Accompanied by Stress, on the Tensile Properties of Sheet Duralumin, H. S. Rawdon. *Am. Soc. Testing Matls.—Advance Paper for mtg.* June 24-28, 1929, no. 42, 18 pp., 8 figs.

Duralumin becomes quite weak and brittle occasionally while in service; as result of study carried out by U. S. Bureau of Standards reasons for this behavior have been greatly clarified; corrosion accompanied by repeated bending stresses constitutes very search test for corrodibility; aluminum-coated duralumin is so decidedly better in its behavior to plain duralumin as to leave no uncertainty as to its superiority for purposes where high strength, lightness, and corrosion resistance are conditions to be fulfilled.

DIE CASTING ALLOYS

Die-Casting Alloys and How to Select Them. *Machy. (N. Y.)*, vol. 35, no. 10, June 1929, pp. 733-734.

Information compiled by Alemite Die-Casting and Manufacturing Co., Chicago, with view to helping user of die-castings select alloys from which different castings should be made; general characteristics of aluminum-base alloys; advantages and disadvantages of zinc-base alloys; when tin and lead-base alloys are desirable; choosing alloys on basis of information given in table; tolerances for alloys.

DIES

QUENCHING. Some Notes on Die Quenching. *Machy. (Lond.)*, vol. 34, no. 869, June 6, 1929, pp. 297-298, 3 figs.

Factors producing bad work during quenching dies are discussed, including speed of plunging quenching motion, cross-section of work, and quenching medium.

ELECTRIC FURNACES

ANNEALING. Time of Graphitization Cut Down, H. O. Breaker. *Iron Age*, vol. 123, no. 21, May 23, 1929, pp. 1412-1413, 1 fig.

Description of special design of elevator-type electric annealing furnace of 15 tons capacity which has been in continuous operation at plant of Acme Steel and Malleable Iron Works, Buffalo; malleable iron annealed in furnace in three-day cycle; controlled analysis and observance of laws governing graphitizing are essential.

FOUNDRY. Report on Questionnaire of Electric Furnace Committee of Association of German Foundrymen on Dimensions and Efficiency of Electric Arc Furnaces (Bericht ueber das Ergebnis der Rundfrage des Elektroofenausschusses des Vereins deutscher Giessereifachleute ueber Masse und Leistungen der Elektrolichtbogenoefen). *Giesserei (Duesseldorf)*, vol. 19, no. 16, May 10, 1929, pp. 437-443.

Replies to questionnaire were received from 18 plants, 5 of which were German; results are given, relating to electric equipment of arc furnaces, duration of refining and melting process, and other features of design and operation.

HEAT TREATING. Heat Treating Automobile Parts, F. L. Prentiss. *Iron Age*, vol. 123, no. 24, June 13, 1929, pp. 1625-1629, 9 figs.

Description of electric furnaces installed by Oakland Motor Car Co. for heat-treating gears, pinions, and axles; 14 furnaces, all but one electrically heated; axle shafts pushed lengthwise through furnace; oil-fired pusher furnace normalizes gears; gears annealed in continuous pusher furnace; recuperative furnace carburizes pinions and gears; roller hearth furnaces have double decks; electric rotary-hearth furnace; recording apparatus centrally located.

HIGH FREQUENCY. Progress in Metallurgy and Operation of High-Frequency Furnaces (Fortschritte in Metallurgie und Betrieb des Hochfrequenzofens), H. Newhauss. *Stahl und Eisen (Duesseldorf)*, vol. 19, no. 49, May 9, 1929, pp. 689-694, and (discussion) 694-696.

Electric current consumption of different types of high frequency furnaces is given; production of low-carbon steel free from red embrittlement; other possible applications of high-frequency furnaces, for instance, in a duplicate process combined with cupola; possibilities of decarburizing ferro-chromium and of producing stainless chromium steel; manufacture of furnace lining.

HIGH FREQUENCY. Recent Developments of High-Frequency Electric Induction Furnaces (Les progrés récents des four électriques à induction à haute fréquence), G. Ribaud. *Technique Moderne (Paris)*, vol. 21, no. 8, Apr. 15, 1929, pp. 225-231, 10 figs.

Theory of high-frequency spark alternators and induction furnaces; heating of homogeneous and heterogeneous cylindrical masses; formation of outside layers of highest current density; efficiency for various metals and graphite in induction furnaces; power factor; direct and indirect induction; electromagnetic puddling.

OPERATING COSTS. Costs of Operating Electric Furnaces. *Elec. News (Toronto)*, vol. 38, no. 13, July 1, 1929, p. 43, 1 fig.

Graph showing consumption curves for heating various metals and explanatory notes.

ELECTRIC HEATING

RESISTANCE MATERIALS. Life Tests on Metallic Resistor Materials for Electrical Heating, F. E. Bash and J. W. Harsch. *Am. Soc. Testing Matls.—Preprint*, no. 50, for mtg. June 24-28, 1929, 14 pp., 2 figs.

There are two general types of service: electric appliances, such as toaster and electric irons; and electric furnaces; tests were made on effects of all variables encountered in life test, most important of these being; temperatures, heating and cooling cycles, mounting, dimensions of test specimens, atmosphere and voltage variation.

FURNACES

ANNEALING, NORMALIZING. Conveyor Is Independent in Furnace for Normalizing Sheets. *Iron Trade Rev.*, vol. 84, no. 20, May 16, 1929, pp. 1330-1331, 1 fig.

Description of furnace installed by West Penn Steel Co. for open annealing full finished sheets; installation is 190 ft. long and 15 ft. wide; disk-type continuous conveyor; disk beam mounted in watercooled shafts rotated through beveled gear drive, driven by 15 hp. variable-speed motor.

HEATING. Relations between Heating of Rolled Metal and Ingot-Heating Furnace Operation (Zusammenhaenge zwischen der Durchwaermung des Walzgutes und dem Stossofenbetriebe), F. Wesemann. *Archiv. fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 2, no. 11, May 1929, pp. 707-724, 17 figs.

Results of tests carried out on ingot-heating furnaces to investigate relations between heating of material, its surface temperature, and heat circulation in furnace; it is shown that extent to which metal is heated depends to great extent on degree of heat absorption in rear of furnace and on rapidity of heating in foremost section. Bibliography.

MELTING, GAS FIRED. A New Type of Brass Melting Furnace, A. Forward. *Metal Industry (N. Y.)*, vol. 27, no. 5, May 1929, pp. 237-238, 2 figs. See also *Am. Gas Assn. Monthly*, vol. 11, no. 5, May 1929, pp. 269-272, 4 figs.

Description of brass melter consisting of revolving metallic retort externally fired and enclosed in shell heavily insulated, and refractory lined for heat concentration; atmospheric control and fuel conservation; ten gas burners, five on each side; furnace developed through research sponsored by American Gas Assn. and American Gas Furnace Co.

METALLURGICAL, CONTINUOUS. Furnaces for Continuous Production (Oefen fuer Betriebe mit fliessender Fertigung (Fliessoefen), G. Bulle and C. Floessel. *Stahl und Eisen (Duesseldorf)*, vol. 49, nos. 24 and 25, June 13 and 20, 1929, pp. 865-874, and 903-910, 45 figs.

Description of different types of continuous furnaces; various types of conveying equipment; firing process; cost data is given for annealing, hardening, heating, case-hardening, forging, and rolling-mill, and other types of furnaces; advantages and disadvantages of continuous furnaces.

METALLURGICAL—REGENERATORS. The Theory and Application of Regenerative Principles in the Steel Industry, T. J. McLaughlin. *Am. Iron and Steel Inst.—Advance Paper for mtg.* May 24, 1929, 30 pp., 14 figs.

Discussion of fuel; thickness of brick and area of openings; effect of increased checker depth and efficiency of regenerators; distribution of waste gases and air; dust deposits; regeneration in blast-furnace stoves; application to soaking pits and reheating furnaces.

HARDNESS TESTING

The Differential Method for Measuring the Thickness of Hard Cases without Sectioning Them, E. G. Herbert and P. Whitaker. *Iron and Steel Inst.—advance paper*, no. 6, May 1929, 10 pp., 6 figs. partly on supp. plate. See also *Engineering (Lond.)*, vol. 127, no. 3304, May 10, 1929, pp. 593-594, 4 figs.

Method described consists in making two different hardness tests; primary test which measures only one variable hardness of case, and secondary test which measures combined effect of two variables, hardness and thickness of case; two hardness tests used in differential method are pendulum time test and Brinell test.

The Nature of Hardness and the Hardness of Metals, C. H. Desch and H. O'Neill. *Foundry Trade Jl. (Lond.)*, vol. 40, no. 665, May 16, 1929, pp. 364-365.

Subject of hardness is of considerable interest to chemist as well as to engineers; nature of hardness is discussed with reference to static test under certain conditions of high velocity, real test of hardness, ordinary tensile test, cohesive strength of material, internal repulsive pressure, hardening by cold work, cold workings, and resistance to crystal slip; hardness of metals discussed with reference to Brinell test, and difficulties with manganese steel from hardness point of view. Paper presented before joint meeting of Soc. of Chem. Industry and Instn. Mech. Engrs.

CLOUDBURST PROCESS. Cloudburst Process for Hardness Testing and Hardening, E. G. Herbert. *Am. Soc. Steel Treating—Trans.*, vol. 16, no. 1, July 1929, pp. 77-92 and (discussion) 92-96, 15 figs.

If piece of steel be placed in jet of hard steel balls moving at high velocity, balls will rebound from hard steel surface leaving it unaffected but will roughen soft surface; by this means exact shape and location of soft areas may be determined, whereas by present methods only one or few selected spots are tested; it is possible to superharden steel surface artificially by bombarding surface with hard steel balls; it is believed that process will be used to superharden gear teeth and other parts where extreme hardness is necessary.

HARDNESS TESTING MACHINES

The Monotron Hardness Indicator. *Machy. (Lond.)*, vol. 34, no. 870, June 13, 1929, p. 331.

Description of machine developed by Shore Instrument and Manufacturing Co., Jamaica, N. Y., which is of constant-size impression type, load required to give definite standard penetration, as measured by lower dial indicator, being read off from larger dial.

New Hardness Testing Machine (Nouvelle machine à mésurer la dureté), J. Pomey and P. Voulet. *Revue de Métallurgie (Paris)*, vol. 26, no. 5, May 1929, pp. 238-247, 7 figs.

Microscopic impression is formed by a diamond cone, angle of which was chosen to give coefficient of hardness coinciding with Brinell hardness; load of several kilograms is applied directly to diamond; measure of

diameter is made by metallographic microscope; advantages and applications of apparatus are set forth; comparison with Brinell method.

HARDNESS TESTING INSTRUMENTS

Busch-Schumann Projector for Reading of Brinell Hardness Ball Impressions (Der Busch-Schumann Projektor ein Ablesegeraet fuer Brinellsche Kugeleindruecke), Doehmer. *V. D. I. Zeit. (Berlin)*, vol. 73, no. 22, June 1, 1929, p. 764, 2 figs.

Detailed description of instrument for measuring depth of indentation with precision of 0.001 mm.

HEAT TREATING EQUIPMENT

Heat Treating Equipment. *Machy. (Lond.)*, vol. 34, no. 870, June 13, 1929, pp. 321-330, 17 figs.

Recent advances in design and application are considered; attention which furnace makers are directing towards mechanical designs; heat treatment of aluminum and other light alloys; layout of equipment; rotary electric furnace; rotary gas furnace; gas case-hardening furnaces; continuous carburizing furnace; gas and electric carburizing furnaces; nitrogen hardening; furnaces for aluminum and light alloys; annealing aluminum; annealing castings and forgings.

IMPACT TESTING

NOTCHED BAR. Dangers of Notch Effects (Ueber die Gefahren der Kerbwirkung), Roetscher. *Maschinen-Konstrukteur (Leipzig)*, vol. 62, no. 10, May 15, 1929, pp. 218-222, 27 figs.

Distribution of forces and increase of stresses in various machine parts resulting from holes, grooves, notches, etc., are discussed.

NOTCHED BAR. Stress and Strain Relations in the Impact Test, R. Yamada. *Metallurgist (Supp. to Engineer)*, May 31, 1929, pp. 78-79.

Investigation of problems associated with notched-bar impact testing using nickel-chromium and carbon steels containing 0.1, 0.3 and 0.5 per cent carbons. Abstract of Report No. 7 of Tohoku Imperial University Science Reports. See reference to original work in Eng. Index 1928, p. 970.

REPEATED BLOW. Repeated Blow Impact Tests, R. H. Greaves. *Metallurgist (Supp. to Engineer)*, May 31, 1929, pp. 67-68.

Repeated-blow test is complex test having factors in common with single-blow test on notched bars and with fatigue test; it appears to be established that for steels of ordinary properties endurance under variety of conditions is determined by tensile strength and related properties rather than by any other factor; experiments were made with Stanton machine and square notch test piece by J. M. Lessells. Communication from Research Dept., Woolwich.

IRON CORROSION

Organic Type Inhibitors in the Acid Corrosion of Iron, J. C. Warner. *Am. Electrochem. Soc.—Advance Paper*, no. 20, for mtg. May 27-29, 1929, pp. 221-230, 2 figs.

Evidence is presented substantiating theory that inhibitors of organic type function by increasing overvoltage required for deposition of hydrogen; experiments indicate that any substance which will form large positively charged oily iron, or positively charged, oily, colloidally dispersed particles, in acid solution, should inhibit acid corrosion of iron if substance cannot be electrolytically reduced.

Observation on the Corrosion of Iron, J. F. G. Hicks. *Jl. of Phys. Chem.*, vol. 33, no. 5, May 1929, pp. 780-790, 4 figs.

Primary cause of corrosion of iron is actual dissolving of iron in water; this takes place before any other chemical action starts; film of liquid water adhering to metallic surface undergoing corrosion is necessary to this dissolving process.

IRON ALLOYS

DESULPHURIZATION. The Elimination of Sulphur from the Alloys of Iron, K. Gierdziejewski. *Foundry Trade Jl. (Lond.)*, vol. 40, no. 670, June 20, 1929, pp. 465-466, 1 fig.

Desulphurization of bath by cooling; desulphurization using higher contents of Mn in metal and in slag; desulphurization by means of basic slags; one of qualities of Walter's desulphurizing process is that intensive activity of reactions, reducing Fe and MnO and decreasing chemical losses, reduces favorable conditions for elimination of dissolved gases by making metal boil. Paper presented before Int. Foundrymen's Congress.

IRON-CARBON ALLOYS

Two-Space Models of Equilibria in the System Iron-Carbon-Oxygen (Ueber zwei zusammengehoerige raemliche Modelle zur Darstellung der Gleichgewichte im System Fe-C-O), E. Jaenecke. *Zeit. fuer anorganische u. allgemeine Chemie (Leipzig)*, vol. 178, no. 1-3, 1929, pp. 73-96, 13 figs.

Two new models are constructed to establish factors which determine equilibrium in system Fe-C-O.

IRON-NICKEL ALLOYS

Recent Developments in Nickel Alloyed Iron, Steel and Cast Iron, J. S. Vanick. *Iron and Steel of Canada (Gardenvale, Que.)*, vol. 12, no. 5, May 1929, pp. 127-129, and 149-151, 3 figs.

Various properties of nickel iron and steel alloys which make them suitable for application in steel-treating apparatus and electrical industry; permalloy and hypernick; carbon-nickel alloys; processing low-thermal-expansion properties such as invar, elinbar, and platinite within 30 to 40 per cent nickel range; low-carbon-nickel-iron alloys in 8 to 20 per cent of stainless type of low-carbon alloy steels; application of nickel for steam boilers.

Nickel-Iron System (Zur Kenntnis des Systems Nickel-Eisen), G. J. Sizoo and C. Zwikker. *Zeit. fuer Metallkunde (Berlin)*, vol. 21, no. 4, Apr. 1929, pp. 125-126, 1 fig.

Simple and rapid process for production of single-crystal wires from nickel and nickel-iron is described; easy machinability of these crystals makes it possible to study electric properties of nickel-iron alloys in relation to composition of pure specimen; specific electric conductivity and resistance temperature coefficient have been measured for series of alloys.

Recent Developments in Nickel Alloyed Iron, Steel and Cast Iron, J. S. Vanick. *Iron*

and *Steel of Canada (Gardenvale, Que.)*, vol. 12, no. 6, June 1929, pp. 157-159, 173, and 175, 2 figs.

Important new development in low-carbon nickel steels is discussed; applications of cast steel containing from one to three per cent nickel; properties and uses of steels 0.30 to 0.45 C. steels 0.40 to 0.55 C. over 0.55 C., and nickel cast iron; obtaining properties of increased strength; heat and corrosion resistance; special alloys.

IRON METALLOGRAPHY

Martensite System (Ueber das Martensitsystem), K. Gebhard. H. Hanemann and A. Schrader. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 2, no. 11, May 1929, pp. 763-771, 31 figs.

Use of electrocardiograph in thermal investigation of martensite system is described; heterogeneity of martensite and existence of second metastable system of iron-carbon alloys are confirmed; physical properties and structure are in agreement with this system; phases of martensite system and its characterization are established.

Single Crystal of Iron (Ueber Einkristalle aus Eisen), H. Gries and H. Esser. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 2, no. 11, May 1929, pp. 749-761, 22 figs.

Method of producing single crystals; influence of initial grain size on recrystallization in case of pure iron; surface occurrence and nature of deformation and its elimination; recrystallization temperature and duration of annealing; results of recrystallization tests on electrolytic iron with varying oxygen content; change in crystal orientation with rolling of single crystal.

Change in Microstructure of Iron at A-3 Transformation Point, B. A. Rogers. *Am. Inst. Min. and Met. Engineers.—Tech. Publications*, no. 218, 1929, 13 pp., 9 figs.

Investigation confirms results of previous investigators in that there is no appreciable change in microstructure of iron until A-3 point is reached; if iron is pure, change comes simultaneously with changes in heat content and space lattice; results also confirm theory that presence of element which forms eutectoid with iron reduces distinctness of eruptive wave or causes it to disappear altogether; sudden change in microstructure is connected with fairly abrupt shift in space lattice.

POLYMORPHISM. Influence of Elements on Polymorphism of Iron (Ueber den Einfluss der Elemente auf den Polymorphismus des Eisens), F. Wever. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 2, no. 11, May 1929, pp. 739-748, 17 figs.

Notes on classic and atomic metallography; structure of mixed crystals and metal compounds; structural analogies with copper alloys; polymorphism of iron as basis for periodic system of its alloys; four types of iron alloys; relations between behavior and atomic volumes or atomic radius.

IRON AND STEEL CORROSION

A Critical Study of the A. S. T. M. Corrosion Data on Uncoated Commercial Iron and Steel Sheets, V. V. Kendall and E. S. Taylerson. *Am. Soc. Testing Matls.—Preprint*, no. 37, for mtg. June 24-28, 1929, 16 pp., 17 figs.

Data resulting from atmospheric and total-immersion corrosion tests conducted by Society's Committee A-5 on Corrosion of Iron and Steel have been analyzed by statistical method to determine effect on corrosion resistance of copper, phosphorus, manganese, and sulphur, and their combinations; results are given in form of curves; under total-immersion conditions effect of ordinary variations in composition is secondary to external influences.

PREVENTION. The Influence of Corrosion Accelerators and Inhibitors on Fatigue of Ferrous Metals, F. N. Speller, I. B. McCorkle and P. F. Mumma. *Am. Soc. Testing Matls.—Advance Paper*, no. 41, for mtg. June 24-28, 1929, 12 pp., 4 figs.

Data reported follow report given last year in which marked influence of inhibitors in preventing corrosion fatigue was demonstrated; in present paper influence of wide range of chloride concentrations on corrosion fatigue of similar standard steel is reported, and influence of various amounts of inhibitors in retarding corrosion fatigue with same range of chloride concentrations.

IRON AND STEEL TESTING

A Method of Treating Data on the Lives of Ferrous Materials, R. F. Passano and A. Hayes. *Am. Soc. Testing Matls.—Preprint*, no. 38, for mtg. June 24-28, 1929, 12 pp., 5 figs.

It is shown that proper study of life of ferrous metal must involve adequate number of samples; when such numbers are available, results can be obtained by distribution principles when proper classification into groups has been made; value of a, most probable life, represents average service life of group; the higher is a, more desirable is material or condition.

MANGANESE STEEL

HEAT TREATED. Heat-Treated Low-Manganese Steels, E. E. Thum. *Iron Age*, vol. 123, no. 25, June 20, 1929, pp. 1691-1695, 5 figs.

Applications of heat-treated low-manganese steels are discussed, covering shock-resisting castings, anchor chain, high-test welding rod, carburizing steel, heat-treated forgings, bolts for high temperature steam valves, rifle barrels, leaf and helical springs, shear blades, and gages (non-deforming); oil quenched and drawn castings, forgings and machined parts of intermediate properties and costs becoming popular in American shops.

STRUCTURE. A Study of the Constitution of High Manganese Steels, V. N. Krivobok. *Am. Soc. Steel Treating*—TRANS., vol. 15, no. 6, June 1929, pp. 893-928 and (discussion) 928-956, 52 figs.

Constitutents of austenitic manganese steel (Hardfield steel) under different conditions of treatment; cold working followed by heating to certain temperatures, brings about decomposition of original austenite; theory of decomposition; suggestion that allotropic transformation takes place; formation of carbide constituent, as influenced by cold working and heating; theory of martenization; occurrence of martensite needles in manganese austensite is studied.

METALS

CORROSION. Corrosion of Metals as Influenced by Surface Films, F. N. Speller. *Mech Eng.*, vol. 51, no. 6, June 1929, pp. 431-434.

Review of important facts developed; in-

fluence of well-known alloying metals on film-forming capacity of iron; conclusion is reached that rust-resisting alloys such as high-chrome iron and stainless steel probably owe their resistant properties to stable films formed under certain conditions and therefore that life of these metals is more directly dependent on stability of film formed than on initial tendency of metal to corrode; some metals have much more of this self-protecting property than others.

HARDENING. Cold and Hot Working of Metals, W. Rosenhain. *Rolling Mill Jl.*, vol. 3, no. 5, May 1929, pp. 215-217.

Bearing of recent results in testing of creep and work softening of metals on present theories of work hardening and plastic deformation discussed; influence of irregular intercrystalline structure on behavior of metal during deformation; limit of work hardening; work hardening due to lattice distortion; crystal junctions. Abstract of paper presented before Int. Congress for Testing Matls.

HEAT CONDUCTIVITY. The Thermal Conductivities of Copper and Nickel, and Some Alloys of Nickel, W. C. Ellis, F. L. Morgan and G. F. Sager. *Rensselaer Polytechnic Inst.* Bul., no. 21, Sept. 1928, 23 pp.

King's method was found to be very satisfactory for determination of thermal conductivity of metal and alloy wires; ratio of thermal to electrical conductivity for alloys investigated was found to be somewhat higher than for elementary metals, and not even approximately constant; values were of same order of magnitude.

PROPERTIES. Some Ideas About Metals, O. Lodge. *Metal Industry* (*Lond.*), vol. 34, nos. 20 and 21, May 17 and 24, 1929, pp. 489-492 and 511-514.

May 17: How author failed to discover Hall effect; Hall's discovery; metallic conduction; theory of gases; radiation and deflection; electricity and light and gravitation; thermoelectricity; basis of frictional electricity; Thomson effect. May 24: Kinds of electrical conduction; cling and velocity; planetary electrons of copper; number of free electrons involved; electronic inertia; counting electrons; conductivity of some alloys; Mathiessen's work; superconductivity; perpetual motion. (Concluded.) Paper presented before Inst. of Metals.

PROPERTIES. Some Ideas About Metals, O. Lodge. *Metal Industry* (*Lond.*), vol. 34, no. 19, May 10, 1929, pp. 454-466.

Remarks on state of mind which makes discoveries, and on state of mind which just misses them; Roentgen's successful investigation; some difficulties in radiation theory; Boehr's doctrine of atomic structure; verifying Zeeman effect; opportune discoveries; failure of experimenter to make discovery because deterred by theoretical considerations. Abstract of paper presented before Brit. Inst. of Metals.

TEMPERATURE EFFECTS. Special Metals Required for Extreme Temperatures and Pressures, A. E. White and C. L. Clark. *Power*, vol. 69, no. 22, May 28, 1929, pp. 898-899, 4 figs.

Metals to be used for temperature from 700 to 900 deg. and over; ferrous and nonferrous divisions and group, including plating with metals, as chromium, nickel, etc., and nitriding; curves showing properties of 0.13 per cent carbon steel at high temperature; expansion results, safe working loads and proportioned limit values for 38 per cent carbon-steel tubing; flow tests on chromium-tungsten steel at 1000 deg. Fahr. with various selected steels.

TORSIONAL MODULUS. Torsional Modulus of Carbon Steel, Phosphor Bronze, Brass and Monel Metal, W. P. Wood. *Am. Soc. Steel Treating*—TRANS., vol. 15, no. 6, June 1929, pp. 971-981 and (discussion) 981-985.

Torsional modulus of elasticity is defined and its general relation to modulus of elasticity in tension and compression is discussed; review of published work on determination of torsional modulus; of four methods, deflection method was chosen; determinations were made upon three types of steel, phosphor bronze, brass and monel metal; results are given in form of averages.

METALS ANALYSIS

ELECTROLYTIC. New Apparatus for Electrolytic Analysis, H. J. S. Sand. *Analyst* (*Cambridge*), vol. 54, no. 638, May 1929, pp. 275-282, 5 figs.

Apparatus is based on that used by author for deposition and separation of metals by electrolysis; outer electrode surrounds inner everywhere, except below, being placed as close as possible to bottom of beaker.

METALS CORROSION

Corrosion of Metals Under Cyclic Stress, D. J. McAdam, Jr. *Am. Soc. Testing Matls.—Advance Paper*, no. 40, for mtg., June 24-28, 1929, 54 pp., 23 figs.

Résumé of previous work, outline of continued investigation, and description of material and methods; effect of stress, time, and number of cycles on corrosion; metals investigated are ordinary steels, duralumin, monel metal, and stainless iron; "damage" as used in paper means lowering of fatigue limit due to corrosion with or without cyclic stress; net effect of cyclic stress on corrosion is illustrated by constant-net-damage diagram.

METALS CUTTING

Le Travail des Metaux aux Machines-Outils, J. Androuin. Paris, J. B. Bailliere et fils 1929, 499 pp., illus., 80 fr.

Detailed study of manner in which tools act on material, both with respect to quality and rapidity of action; in first part of book are treated general problems, such as action of tools on metal, tool steels, and their treatment, economical working conditions, and tool speeds; second part is devoted to peculiarities of various processes of working.

METALS DUCTILITY

Some Developments in Ductility Testing, C. N. Fletcher. *Machy.* (*Lond.*), vol. 34, no. 870, June 13, 1929, pp. 336-337, 5 figs.

Details of large machine manufactured by Olsen suitable for ductility testing of materials; up to ¼-in. thickness with maximum load of 35,000 lb. cupping being automatically measured by dial gage to 0.001 in. load measured hydraulically and rupture point is noted by instantaneous drop of pressure; Olsen, lever weighing type, ductility testing machine; tools employed on Olsen lever weighing type ductility testing machine; Olsen Williams dynamic ductility testing machine.

METALS TESTING

The Mechanical Testing of Materials, R. W. Bailey. *Metropolitan Vickers Gaz.* (*Manchester*), vol. 11, no. 193, Apr. 1929, pp. 252-256, 12 figs.

Physical properties of forged steel rotors and of coil binding rings of turbines were determined.

Tensile Strength and Hardness of Metals (Zugfestigkeit und Haerte bei Metallen), O. Schwarz. *V. D. I. Zeit.* (*Berlin*), vol. 73, no. 23, June 8, 1929, pp. 792-797, 16 figs.

Practical significance of ball-hardness, coefficient; nonferrous metals, with exception of aluminum and its alloys, show no linear relation between Brinell hardness and tensile strength; curves showing relation between ductility, tensile strength, and Brinell hardness of copper, brass, aluminum, duralumin and cast iron; relation between hardness and other properties at high temperatures. Abstracted from Forschungsarbeiten auf dem Gebiete des Ingenierwesens, no. 313, 1929.

The Mechanical Testing of Materials, R. W. Bailey. *Metropolitan-Vickers Gaz.* (*Manchester*), vol. 11, no. 194, May 1929, pp. 266-275, 24 figs.

Testing methods for discovery of defects; magnetic methods; principle iron-dust test; arrangement of magnetizing apparatus for crack detection in gear pinions; apparatus and form of test piece in embrittlement test; embrittling effect of high temperature on 3½ per cent nickel steel subjected to stress; abrasion testing machine; turbine blades under vibration.

BRITTLENESS. Metals Unaffected by Embrittlement Needed, F. G. Straub. *Power*, vol. 69, no. 22, May 18, 1929, pp. 902-903, 2 figs.

Embrittlement tests on various kinds of steel; testing equipment; tabulation of data regarding chemical analysis and tension tests of metals tested; effect of chemical composition on rate of embrittlement. Abstract of Univ. of Illinois—Eng. Experiment Station—Bul. no. 177.

METALLOGRAPHY

Metallography Simplified for Practical Use in Shop, E. Preuss, G. Berndt and M. v. Schwarz. *Iron Trade Rev.*, vol. 84, no. 22, May 30, 1929, pp. 1465-1466 and 1474, 5 figs.

Occurrence of coarsest grains will depend upon degree of deformation, annealing temperature, and perhaps duration of annealing as well as upon chemical composition of material; cold working creates internal stresses which cause cracks and particular sensitivity to hydroxides, especially sodium hydroxide; methods of discovering fine cracks.

Metallography Simplified for Practical Use in Shop, E Preuss, G. Berndt and M. v. Schwarz. *Iron Trade Rev.*, vol. 84, no. 20, May 16, 1929, pp. 1332-1334, 13 figs.

Effects produced by methods of processing steel in finishing stages are discussed; rolling and cold working of steel further explained; more examples of deformations below 625 deg. Cent. are given. (Continuation of serial.)

Report of Committee E-4 on Metallography. *Am. Soc. Testing Matls.—Preprint*, no. 25, for mtg. June 24-28, 1929, 8 pp., 10 figs. on supp. plates.

Developments on preparation of samples are presented; report of sub-committee on X-ray crystal analysis; report of special committee on standard micrographs for comparison of grain sizes.

MICROSCOPES

Microscope for Brinell Tests. *Metal Industry* (*Lond.*), vol. 34, no. 22, May 31, 1929, p. 534, 2 figs.

Description of Busch-Schumann projector-type microscope with which it is claimed, image of Brinell ball impression, even when lipped rim is produced, appears at one, magnified ten times and sharply focussed on ground-glass screen as soon as instrument is set up over spot to be measured.

INTROSCOPES. The Foster Introscope. *Machy. Market* (*Lond.*), no. 1492, June 7, 1929, p. 527, 4 figs.

Description of device for detecting surface flaws in small bores and other positions of machine parts where it is impossible to apply ordinary microscope; device was developed by Foster Instrument Co.

NICKEL

PROPERTIES. Physical and Mechanical Properties of Nickel, P. D. Merica. *Am. Soc. Steel Treating*—TRANS., vol. 15, no. 6, June 1929, pp. 1054-1059, 6 figs.

Recommended Practice Committee release concerning structure and change of state of nickel; physical, mechanical, and technologic properties and metallographic structure. Bibliography.

NICKEL ALLOYS

Constitution of Nickel-Carbon Alloys, N. B. Pilling and T. E. Kihlgren. *Am. Soc. Steel Treating*—TRANS., vol. 16, no. 1, July 1929, pp. 171-172, 1 fig.

Recommended Practice Committee Release. Carbon has limited solubility in molten nickel; addition of carbon to nickel progressively lowers melting point from 1452 to 1318 deg. Cent., at which temperature eutectic is formed with 2.2 per cent carbon, carbon appearing as graphite; equilibrium for carbon concentrations greater than 2.2 per cent has not been satisfactorily worked out and data are meager; carbon evidently has little effect on vapor pressure of nickel. Bibliography.

NICKEL - COPPER ALLOYS

Study of Nickel-Copper Alloys (Etude des alliages nickel-cuivre), A. Krupkowski. *Revue de Métallurgie* (*Paris*), vol. 26, no. 4, Apr. 1929, pp. 193-208, 19 figs.

Thermoelectric properties and dilatation are discussed; results of measurements; electromotive force of dissolution; hardness measurements; micrographic and radiographic analysis.

NICKEL METALLOGRAPHY

Crystal Size and Magnetic Properties of Pure Nickel (Ueber den Zusammenhang zwischen Korngroesse und magnetischen Eigenschaften beim reinem Nickel), G. J. Sizoo. *Zeit. fuer Physik* (*Berlin*), vol. 53, no. 5/6, Feb. 19, 1929, pp. 449-457, 7 figs.

Conditions for recrystallization with nickel are determined; only when manganese contents does not exceed 0.2 per cent can recrystallization phenomena be obtained by mechanical-thermal methods; twinning occurs frequently; magnetic properties are investigated as function of crystal size.

NICKEL METALLURGY

Theory, Practice and Nickel, W. T. Griffiths. *Metal Industry (Lond.)*, vol. 34, nos. 15 and 16, Apr. 12 and 19, pp. 363-365 and 399-400.

Apr. 12: Mond carbonyl process for producing metal; use for electrodeposition; nickel-iron alloys; nickel-iron alloys in submarine cables; constancy of permeability. Apr. 19: Invar in machinery parts; application to aluminum pistons; nickel-copper alloys; nickel-chromium alloys; development of works technique. Paper read before Inst. of Metals.

NICKEL STEEL TESTING

Tensile Tests at High Temperatures (Les essais de traction à chaud), L. Guillet, J. Galibourg and M. Samsoen. *Génie Civil (Paris)*, vol. 94, no. 22, June 1, 1929, p. 528, 1 fig

Results of further tests of tensile strength of nickel and nickel-chromium steels at 450 deg. Cent.

NITRIDATION

Hardening Steel With Nitrogen, V. O. Homerberg. *Iron Age*, vol. 123, no. 23, June 6, 1929, pp. 1562-1565, 6 figs.

Further discussion of how special alloy steels are nitrided with ammonia gas; details of equipment; analyses and properties of nitralloy; aluminum ranks first as nitride base; heat treating done before nitriding; special type of furnace needed; how ammonia dissociation is found.

Hardening Steel with Ammonia, V. O. Homerberg. *Iron Age*, vol. 123, no. 26, June 27, 1929, pp. 1759-1761, 6 figs.

Necessity for complete removal of decarburized layer before nitriding; nitralloy under microscope; how such hardened steel wears; corrosion resistance a valuable property.

Obtaining Wear Resistance by Nitriding, J. B. Nealy. *Machy. (N. Y.)*, vol. 35, no. 10, June 1929, pp. 727-729, 1 fig.

Discussion of how nitralloy steels are heat-treated to improve physical properties and nitrided to obtain superior wearing surface; analyses and tests of steels adapted for nitriding process; comparative hardness of carburized and nitrided steels; preparation of work for treatment; auxiliary equipment employed; control of gas flow and furnace temperature.

Nitrogen Hardening and Its Advantages. *Machy. (Lond.)*, vol. 34, no. 869, June 6, 1929, pp. 293.

Description of recently developed method of obtaining surface hardness on alloy-steel parts, which may supercede ordinary case-hardening for many purposes; steels which can be nitrided; heat treatment preliminary to nitriding; how nitriding process is carried out; not advisable to anneal nitrided part.

NONFERROUS METALS

FATIGUE. Fatigue Studies of Nonferrous Sheet Metals, J. R. Townsend and C. H. Greenall. *Am. Soc. Testing Matls.—Advance Paper for mtg.* June 24-28, 1929, no. 44, 12 pp., 12 figs.

Paper describes development of fatigue test machine for sheet metals and gives results of fatigue tests on five alloys of alpha-brass, one alloy of nickel-silver, one alloy of phosphor-bronze, and Everdur; results indicate that cold work raises endurance limit but not proportionally to increase in tensile strength produced by same cause; micrographs are shown indicating that fatigue failure of metals investigated is transcrystalline.

RESEARCH. British Nonferrous Metals Research Association. *Metal Industry (Lond.)*, vol. 34, no. 21, May 24, 1929, pp. 510 and 515-516.

Atmospheric corrosion and tarnishing of nonferrous metals; die-casting alloys research; gases in copper castings; copper locomotive fire-box stay rods; properties of lead with special reference to cable sheathing and other high-grade lead; improvement of working properties of zinc; survey of annealing furnace practice; improved alloys for high temperature service; electrodeposition; metallurgical applications of spectroscope; spotting out; nickel electrodeposition; oxidation of copper; aluminum founding; research work completed before December 31, 1928, is listed.

TESTING. Physical Properties and Methods of Test for Some Sheet Nonferrous Metals, J. R. Townsend, W. A. Straw and C. H. Davis. *Am. Soc. Testing Matls.—Preprint for mtg.* June 24-28, 1929, no. 46, 36 pp., 20 figs.

Continuation of investigation undertaken to secure simple and reliable method test and development of commercial test limits; Rockwell hardness and tensile strength limits are given for four alloys of brass, and two alloys each of nickel-silver and phosphor-bronze; grain size limits are given for annealed brass, nickel-silver, and phosphor-bronze sheet; refinements in calibration of Rockwell tester by sheet; refinements in calibration of Rockwell tester by using standard test blocks are given.

OPEN-HEARTH FURNACES

DESIGN. Large Open-Hearth Furnaces, F. A. King. *Am. Iron and Steel Inst.—Advance Paper for mtg.* May 24, 1929, 10 pp., 3 figs. See also abstract in *Iron Trade Rev.*, vol. 84, no. 22, May 30, 1929, pp. 1462, 1463.

Discussion of size and capacity of open-hearth furnaces; plant of Weirton Steel Co. at Weirton, W. Va., includes 12 furnaces of 150 to 350 tons capacity; experience obtained from operation shows increasing economic efficiency and quality progress.

FUELS. The Use of Blast Furnace and Coke Oven Gas in Open-Hearth Furnace, F. E. Leahy. *Am. Iron and Steel Inst.—Advance Paper for mtg.* May 24, 1929, 16 pp. See also abstract in *Iron Age*, vol. 123, no. 22, May 30, 1929, pp. 1486-1488.

General use and specific applications of mixed gas; use of blast-furnace gas; heat value of various mixtures; open-hearth furnace construction and operation; flame temperature and heat transfer from flame.

OPEN-HEARTH FURNACE PRACTICE

Thresh Out Open-Hearth Problems. *Iron Age*, vol. 123, no. 21, May 23, 1929, pp. 1419-1421 and 1463.

Review of Cleveland Meeting of Open-Hearth Committee of American Institute of Mining and Metallurgical Engineers with brief abstracts of papers; Loftus checker installations; chrome brick for lining pan; lining

of furnace ports; patent refractories vs. magnesite; comparison of brick life in roofs; insulation of regenerators and flues; methods for laying checkers.

Furnace Control and Steel Quality. *Iron Age*, vol. 123, no. 22, May 30, 1929, pp. 1495-1496 and 1539-1540.

Review of Cleveland Meeting of Open-Hearth Committee of American Institute of Mining and Metallurgical Engineers, with discussions; maintaining sloping backwalls; stack dampers for furnace; efficient burning of fuel; trend in sizes of new furnaces; effect of extra deep bath on quality; use of 2 per cent silicon Spiegeleisen.

PIPE

STEEL MANUFACTURE. Manufactures Riveted Steel Plate Water Pipe Progressively, E. A. Shaner. *Iron Trade Rev.*, vol. 84, no. 25, June 20, 1929, pp. 1653-1657, 9 figs.

Description of scheme of progressive manufacture which has been applied to steel pipe fabrication in plant of Witt-Humphrey Steel Co., South Greensburg, Pa.; growing demand for large sizes in quantity has developed methods for mass production; asphaltum coating is applied after riveting; riveters served by cranes; multitple automatic punch consisting of two opposed gang punches with hand operated spacing table between.

RAILS

PROPERTIES. Investigations of Influence of Rolling Temperature on Properties of Rails (Untersuchungen ueber den Einfluss der Walztemperatur auf die Eigenschaften der Schienen), W. Voigt. *Stahl u. Eisen (Duesseldorf)*, vol. 49, no. 23, June 6, 1929, pp. 843-845, 6 figs.

Author refers to tests described by R. Stamper in Feb. 7th issue of this journal, and claims that same tests were carried out with carbon steel of medium hardness with p.36 per cent carbon 0.26 per cent silicon, and 0.81 per cent manganese, at Julienhuette, Bobrek, results of which are given; discussion follows between author, R. Stamper, and F. Torkar.

WEAR. Comparative Observations Made on Rails During 30 Years (Mémoire sur quelques observations faites sur des rails se trouvant places dans conditions absolument identiques pendant une période de près de trent ans), L. Lubimoff. *Revue de Métallurgie (Paris)*, no. 5, May 1929, pp. 231-237, 3 figs.

Observations were made on rails governed by absolutely identical conditions; rails were on railroad section between Leningrad and Obouchowo, this being chosen in 1889 for testing 196 rails supplied by all rolling mills in Russia, in lengths of 5.19 and 4.34 m.; results are given for period, 1889-1904 and 1904-1928.

SHEET STEEL

AUTOMOBILE BODIES. Steel Sheets for Automobile Bodies, E. S. Lawrence. *Blast Furnace and Steel Plant*, vol. 17, no. 6, June 1929, pp. 864-868 and 881, 3 figs.

Study is given covering various grades of sheet steel required for modern automobile body parts; advent of normalizing marks progressive step; rolling sheet and stamping operations discussed; variety of processing; stamping conditions; prerequisites for body parts; radiator shell has severe requirements; door and window panels require normalized sheet; back panels must have good appearance.

COLD ROLLING. Influence of Reduction of Draft and of Annealing Temperature on Mechanical Properties and Structure of Cold-Rolled Thin Sheets (Einfluss der Stichabnahme und der Gluehtemperatur auf die mechanischen Eigenschaften und das Gefuege von kaltgewalzten Feinblechen), A. Pomp and L. Walther. *Mitteilungen aus dem Kaiser-Wilhelm-Institut fuer Eisenforschung (Duesseldorf)*, vol. 11, no. 2, 1929, pp. 31-35, 6 figs.

Annealing for 3 hrs. at 920 deg. Cent. gave best mechanical properties and uniform structure, and at 650 deg. Cent. was insufficient to remove cold work; tests showed that gage was without effect on deep-drawing properties of annealed sheet.

HEAT TREATMENT. The Normalizing of Sheet Steel, W. Parker. *Engineering (Lond.)*, vol. 127, no. 3310, June 21, 1929, p. 799, 4 figs.

Method of heat treatment in which temperature and cooling cycles are completely under control, and which can be applied with accuracy and certainty to material, has been developed, and is in use in practically all large sheet mills in United States; normalized steel commands much higher price in United States than material which has been box-annealed, owing to its superior qualities.

SPRING STEEL

Selection of Steel for Springs. *Iron Age*, vol. 123, no. 21, May 1929, pp. 1416.

Results of study made at British National Physical Laboratory reported to Iron and Steel Institute; table shows physical properties of quenched and tempered spring steels.

SPONGE IRON

Sponge Iron, A Raw Material for Electric Steel, N. K. G. Tholand. *Am. Electrochem. Soc.—Advance Paper*, no. L, for mtg. May 27, 28 and 29, 1929, 22 pp. 2 figs.

Sponge iron is now commercially produced in Sweden and used as base for manufacture of commercial and highest grade steels; can be made free from silicon and very low in carbon, sulphur, and phosphorus; comparative figures of scrap and sponge iron are shown based on actual heats in electric furnace; physical properties of steels made with sponge iron excel those of steels made from scrap or pig iron.

STAINLESS IRON

Modern Application of Acid-Resisting Iron. *Chem. and Industry (Lond.)*, vol. 48, no. 19, May 10, 1929, pp. 483-485, 2 figs.

Properties of ironac metal are described and its application in plants for manufacture of nitric acid, sulphuric acid, rayon etc.; results of corrosion tests made in course of practical work, with test pieces from large vessels made of ferrosilicon.

STAINLESS STEEL

Alloys of Chromium and Iron, T. H. Nelson. *Iron Age*, vol. 123, no. 22, May 30, 1929, pp. 1478-1482, 8 figs.

Plea for nomenclature; definitions suggested; types being used and why; effect of variations in chromium; higher chromium alloys; chemist and engineer should collaborate; physical structure of welded chromium iron.

STEEL

TEMPERATURE EFFECT. The Application of Science to the Steel Industry, W. H. Hatfield. *Am. Soc. Steel Treating*—TRANS., vol. 16, no. 1, July 1929, pp. 121-154.

Review of work done in determining properties which various steels possess at elevated temperatures; effect of temperature on tensile strength, fatigue properties, impact tests, and effect of corrosion at higher temperatures are discussed; lengthy discussion and much data on various heat-resisting steels are given; many of high-temperature tests were conducted in atmospheres of gases and gas mixtures which approximate conditions under which materials are commonly used in industry; effect of temperature upon steels.

STEEL ANALYSIS

OXYGEN CONTENT. On Oxygen Dissolved in Steel, and Its Influence on the Structure, M. A. Grossmann. *Am. Soc. Steel Treating*—TRANS., vol. 16, no. 1, July 1929, pp. 1-19 and (discussion) 19-56, 21 figs.

It is shown that in regular pack carburizing (box carburizing), steel absorbs oxygen as well as carbon; amount of soluble oxygen present in steel appears to affect microstructure; cementite diffusion (and hence agglomeration) seemingly accounts for phenomenon of split cementite in structures observed in McQuaid-Ehn test, and for structure in boundary cementite in low-carbon steels; solubility of cementite in alpha iron can be indicated on iron-carbon diagram. Bibliography.

SULPHUR DETERMINATION. A Rapid Method for Dissolving High Chromium Steels for the Determination of Sulphur, B. S. Evans. *Analyst (Cambridge)*, vol. 54, no. 638, May 1929, pp. 286-287, 1 fig.

Apparatus was devised in order to permit sample being dissolved first in hydrochloric acid alone, and afterwards oxidized with nitric acid.

X-RAY. Some X-Ray Studies of Cold Worked Steel, F. C. Elder. *Am. Iron and Steel Inst.—Advance paper*, for mtg. May 24, 1929, 22 pp., 29 figs. See also abstracts in *Iron Age*, vol. 123, no. 22, May 30, 1929, pp. 1488-1490, 8 figs., and *Iron Trade Rev.*, vol. 84, no. 22, May 30, 1929, pp. 1458, 1461 and 1474, 12 figs.

Description of adaptation of Hull method of X-ray examination, known as pin-hole method; discussion of changes that take place in pin-hole type X-ray patterns during cold drawing low-carbon steel.

STEEL FOUNDRY PRACTICE

Producing Steel Castings in the Modern Foundry, C. W. Veach. *Foundry*, vol. 57, no. 12, June 15, 1929, pp. 526-528 and 535, 2 figs.

Flow of product through steel foundry is discussed; plan of building which houses furnace; storage; open-hearth furnace of 25-ton capacity which is constructed so that 35 tons may be made if large heat is required; elaborate system of checkers.

STEEL HEAT TREATMENT

Heat Treatment on the Layouts, C. B. Gordon-Sale. *Mech. World (Manchester)*, vol. 85, no. 2213, May 31, 1929, pp. 508-509.

Necessary requirements of layout for heat-treatment operations are discussed; essential features to be considered in deciding upon layout, including condition of service, material employed, machine operations, design of components, and specifications of physical requirements.

TERMINOLOGY. Recommendations for Standardization of Engineering Terms (Vorschlaege fuer die Vereinheitlichung von Fachausdruecken), K. Daeves. *Stahl und Eisen (Duesseldorf)*, vol. 49, no. 24, June 13, 1929, pp. 878-879.

Recommendations proposed by sub-committee of Materials Committee of Verein deutscher Eisenhuettenleute; terms defined include heat treatment, quenching, hardening, annealing, etc.

STEEL METALLOGRAPHY

The Constitution of Steel and Cast Iron Section, F. T. Sisco. *Am. Soc. Steel Treating*—TRANS. vol. 15, no. 6, June 1929, pp. 1027-1042, 3 figs.

After brief review of solid-solution austenite, constitution of martensite is discussed from two viewpoints: that it is solid solution, and that it is aggregate; constitution of troostite based on high magnification metallographic studies of Lucas is explained, and the whole coordinated into theory of hardness of martensite according to Sauveur; why steel hardens by thermal treatment.

MARTENSITE CRYSTALS. On the Nature of Martensite Crystals, K. Honda. *Am. Soc. Steel Treating*—TRANS., vol. 16, no. 1, July 1929, pp. 97-112 and (discussion), 113-120, 7 figs.

Paper deals with nature of martensite, especially with its two kinds, alpha and beta, existence of which is now made very evident by result of X-ray investigation; formation of these martensites was explained by theory of quenching put forward 10 years ago; new view regarding mechanism of tempering of quenched steels was also expressed; broadening of spectral lines of martensites was explained by distortion of iron lattice due to presence of carbon atoms within lattice.

MICROSTRUCTURE. The Microstructure of Rapidly Cooled Steel, J. M. Robertson. *Iron and Steel Inst.—Advance Paper (Lond.)*, no. 12, May 1929, 29 pp., 4 figs.

By cooling small steel specimens in molten metal at various temperatures between 600 and 220 deg. Cent. sequence of structures obtained was investigated; ultimate composition of product of decomposition of austenite appears to vary gradually as transition temperature is lowered; other points are elucidated. Bibliography.

STEEL RESEARCH

The Application of Science to the Steel Industry, W. H. Hatfield. *Am. Soc. Steel Treating*—TRANS., vol. 15, no. 6, June 1929, pp. 986-1026.

Author has divided alloy steels into two groups; first group includes steel produced to obtain excellent mechanical characteristics as result of heat treatment; second group of steels usually contain greater quantities of alloying elements and are intended for purposes such as wear-resisting, acid and heat-resisting, magnet and tool steels, etc.; chromium and chromium-nickel steels in most common use are described.

News of the Society

NATIONAL METAL CONGRESS AND EXPOSITION

THE first Annual National Metal Congress will be held in Cleveland, September 9 to 13, 1929, in conjunction with a huge industrial exposition. Coincidental with the congress will come the eleventh annual meeting of the American Society for Steel Treating and the National Fall meetings of the American Welding Society; Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers; the Iron and Steel Division of the American Society of Mechanical Engineers and the Iron and Steel Division of the American Institute of Mining and Metallurgical Engineers. These societies represent a combined membership of more than 15,000 and the National Metal Congress will mean the assembling in Cleveland of the greatest scientific minds of the metal industry. Here will meet the men who are responsible for the progress of this country in production, treatment, fabrication and use of the various metals, ferrous and nonferrous. Reports on progress made during the year in the field of research will be offered and interesting and highly valuable papers will be read at the various sessions.

When men of metals get together they have in mind progress in every scope of metals and as metals affect every industry, every enterprise and every home, this first annual National Metal Congress takes on additional importance. In addition to the leaders of the industries, representatives of the different chapters of the various societies will be on hand, and Cleveland, for the time being, will be the metal capital of the world. It will be the fount of additional knowledge and the scene of a most comprehensive metals exposition.

In addition to the metals congress there will be assembled in Cleveland's big Public Auditorium the eleventh annual National Metal Exposition in which will be displayed the most modern types of machinery and equipment used by metal using concerns of the country. Demonstrations of the various devices aimed to improve conditions in the processing of metals will be of inestimable value. The Cleveland Public Auditorium with 80,000 square feet of exhibit space will be entirely occupied by the exposition which presents a complete cycle of supplies and equipment used in the production, selection, fabrication, treatment, inspection, welding and application of metals. Over 250 exhibitors have made reservations. A list of these is appended.

The Welding and Cutting Exposition, held under the auspices of the American Welding Society in co-operation with the National Metal Exposition, will afford those in attendance an opportunity to observe the latest and best equipment and development in this field. All other fields of the metal industry will be represented.

Splendid technical programs have been arranged by all of the societies. In the past these sessions have brought together leaders in the steel and iron field, but this year they will assemble many from other branches of the indus-

try. Any one program would in itself be sufficient to bring to Cleveland the outstanding men of the industry,—and with the combined appeal of the large number of technical papers scheduled for presentation and the worth-while comment and discussion which will follow their presentation the members of the societies and their guests will gain much valuable and interesting information from attendance at these sessions.

Campbell Memorial Lecture

The Edward DeMille Campbell Memorial Lecture will be presented by Dr. Albert Sauveur, Gordon McKay Professor of Metallurgy and Metallography at Harvard University, on Wednesday morning, September 11, immediately following the close of the annual meeting of the American Society for Steel Treating. Dr. Sauveur, known, loved and respected as the dean of the American metallurgists, has prepared a splendid lecture entitled "Steel at Elevated Temperatures." Dr. Herbert M. Boylston, Professor of Metallurgy at Case School of Applied Science, will preside as chairman of the memorial session.

Annual Banquet of The American Society For Steel Treating

The annual banquet will be held in the ballroom of the Hotel Cleveland, on Thursday evening, September 12, at 6:30 P. M. This banquet will be up to the usual high standard and some valuable contributions to the progress of enjoyment and entertainment will be provided. All seats are reserved, tables seat 10 and tickets are $5.00 each, which can be secured by addressing the society headquarters in Cleveland or at the registration desk in the Cleveland Public Auditorium. Members of co-operating societies are invited to attend this function.

Hotel Headquarters

The headquarters of the Iron and Steel Division and the Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers and the American Society for Steel Treating will be maintained at the Hotel Cleveland, while the Hotel Statler will be the headquarters for the American Welding Society and the Hotel Hollenden, the headquarters of the Iron and Steel Division of the American Society of Mechanical Engineers.

Members of the various societies may register at their respective hotel headquarters in the morning and in the afternoon at the Cleveland Public Auditorium. This, however, does not apply to the members of the American Society for Steel Treating, who may register at the Auditorium only during the hours the exposition is open.

Technical Sessions

The morning technical sessions of all societies will be held at the various headquarters hotels. The afternoon sessions will be held in the meeting rooms at the Public Auditorium.

The Symposium on Nitriding which has been sponsored by the American

Society for Steel Treating is an all-day session Friday, September 13. This session has to do with one of the most recently developed methods of hardening steel and will have international importance inasmuch as Dr. Adolph Fry, Essen, Germany, and P. F. M. Aubert, Paris, France, will take part in the program.

Ladies' Entertainment

All ladies attending the National Metal Congress and National Metal Exposition will have their entertainment as a single group. This includes the ladies of the five national societies meeting in Cleveland the week of September 9th. The registration of the ladies will be at the hotel which serves their society as headquarters.

Monday, September 9

9:00 A. M.—Registration, Hotel Cleveland, Hotel Hollenden, Hotel Statler.
12:00 M—Automobile ride and luncheon, the Country Club.

Tuesday, September 10

12:30 P. M.—Luncheon and bridge party, Chamber of Commerce.

Wednesday, September 11

2:00 P. M.—Theater Party.

Thursday, September 12

11:30 A. M.—Automobile ride, luncheon and entertainment at Nela Park of the General Electric Company.

Golf

Gold privilege of several clubs are available. Complete information may be secured at the Registration Desk at the Public Auditorium, where privilege cards will be issued.

Daily Newspaper

The *Daily Metal Trade*, published by the Penton Publishing Company, will again issue a special edition during the week of the National Metal Congress. Copies will be available at the various hotels and at the exposition, as well as being mailed to the home address of the members of the American Society for Steel Treating.

American Welding Society

Te program committee of the American Welding Society have arranged an especially fine program for the various technical sessions to be held at the Hotel Statler. Papers on subjects of current interest and setting forth new ideas and adaptations of the welding industry are scheduled for presentation and these meetings should prove instructive and valuable to the members of the society and their guests.

The Welding and Cutting Exposition held under the auspices of the American Welding Society, and in cooperation with the National Metal

Exposition, will afford those in attendance an opportunity to observe the latest and best equipment and development in this field. Approximately 10,000 square feet of exhibit space will be occupied by the exhibitors of the American Welding Society.

Institute of Metals and Iron and Steel Division

The Institute of Metals Division and the Iron and Steel Division of the American Institute of Mining and Metallurgical Engineers will hold their annual fall meeting at Cleveland, the week of September 9.

These divisions have arranged an excellent program of technical sessions and there will be one joint session of the Institute of Metals and the American Society for Steel Treating, to be held at the Public Auditorium on Wednesday afternoon at 2:00 P. M.

The entertainment of both ladies and men will be in cooperation with the other societies.

The annual dinner of these divisions will be held at the Cleveland Hotel on Wednesday evening.

Iron and Steel Division American Society of Mechanical Engineers

The Iron and Steel Division of the American Society of Mechanical Engineers meets for the first time in simultaneous session with the other groups of societies especially devoted to metals and which are sponsors of the National Metal Congress. This division has arranged an interesting technical program of papers as shown in the list of papers which follow.

Drop Forge Supply Association Dinner

The Drop Forge Supply Association, Charles Harman, President, and A. L. Wurster, Secretary, have made arrangements for their annual dinner to be held on Wednesday evening, September 11, at the Winton Hotel and will be followed by an entertainment known as the "Motherwell Entertainment."

Complete information relative to the dinner may be obtained from Mr. Wurster, at the booth of the Heppenstall Forge and Knife Company, Booth No. 82, or by addressing the headquarters at 1020 Drexel Building, Philadelphia.

TECHNICAL PAPERS PROGRAM, NATIONAL METAL CONGRESS AMERICAN SOCIETY FOR STEEL TREATING ELEVENTH ANNUAL CONVENTION

CLEVELAND, SEPTEMBER 9-13, 1929

MONDAY, SEPTEMBER 9

Morning Session

Meeting in Ball Room, Cleveland Hotel
R. M. Bird, Chairman
Frances H. Clark, Vice-Chairman

10:00 A. M.—Introduction.

10:15 A. M.—*Dilatation of Steel During Quenching*—G. M. Eaton, Molybdenum Corp. of America, Pittsburgh.

10:45 A. M.—*The Economical Reuse of Solid Carburizing Materials*—H. B. Knowlton, International Harvester Co., Fort Wayne, Ind.

11:15 A. M.—*The Selection of Case Hardening Steels for Highly Stressed Gears*—H. W. McQuaid and O. W. McMullan, Timken-Detroit Axle Co., Detroit.

Afternoon Session

Meeting Room, Public Auditorium
Bradley Stoughton, Chairman
Robert Atkinson, Vice-Chairman

2:00 P. M.—*Conditions Necessary For Blistering of Metal During Processing*—Dr. Anson Hayes, American Rolling Mill Co., Middletown, Ohio.

2:25 P. M.—*Dendritic Steel*—H. G. Keshian, Chase Metal Works, Waterbury, Conn.

3:00 P. M.—*Improving of Refractory Lining of Heat Treating Furnaces for High Temperature Annealing of Steel Castings*—W. J. Merten, Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.

3:30 P. M.—*Overheating of Steel for Forging*—W. E. Jominy, University of Michigan, Ann Arbor, Mich.

TUESDAY, SEPTEMBER 10

Morning Session

Meeting in Ball Room, Cleveland Hotel
Radelyffe Furness, Chairman
C. H. Herty, Jr., Vice-Chairman

10:00 A. M.—*Production of Electric Steel for Castings*—George Batty, Steel Castings Development Bureau, Philadelphia.

10:30 A. M.—*Slags Produced in Steel Making, Their Effects on the Product and on the Process Itself*—G. A. Dornin, Gathmann Engineering Co., Baltimore.

11:00 A. M.—*Melting Practice for Three Types of Electric Steel*—H. P. Rassbach, Midvale Steel Co., Nicetown, Philadelphia.

11:30 A. M.—*Locomotive Forgings*—Lawford H. Fry, Standard Steel Works, Burnham, Pa.

Afternoon Session

Meeting Room, Public Auditorium
H. J. Stagg, Chairman
A. H. d'Arcambal, Vice-Chairman

2:00 P. M.—*Methods of Tests for Determining the Machinability of Metals in General, With Results*—O. W. Boston, University of Michigan, Ann Arbor, Mich.

2:30 P. M.—*On the Distribution of Hardness Produced By Cold Working*—W. P. Sykes, General Electric Co., Cleveland, and A. C. Ellsworth, Thompson Products Co., Cleveland.

3:00 P. M.—*Inherent Hardenability Characteristics of Tool Steel*—B. F. Shepherd, Ingersoll-Rand Co., Phillipsburg, N. J.

3:45 P. M.—*Some Notes on the Behavior of Carbon Tool Steel on Quenching*—G. V. Luerssen, Carpenter Steel Co., Reading, Pa.

WEDNESDAY, SEPTEMBER 11

Morning Session

Meeting in Ball Room, Cleveland Hotel
Zay Jeffries, Chairman

9:30 A. M.—*Annual Meeting of the American Society For Steel Treating.*

10:30 A. M.—*Campbell Memorial Lecture*, H. M. Boylston, Chairman
Steel At Elevated Temperatures—Albert Sauveur, Harvard University, Cambridge, Mass.

Afternoon Session

JOINT MEETING WITH INSTITUTE OF METALS

Meeting Room, Public Auditorium
P. D. Merica, Chairman
E. C. Bain, Vice-Chairman

2:00 P. M.—*Preparation of Microsections of Tungsten Carbide*—Dr. S. L. Hoyt, General Electric Co., Schenectady, N. Y.
Radiography As a Tool In the Metal Industry—W. L. Fink and R. S. Archer, Aluminum Company of America, Cleveland.
Effects of Cold Working On the Physical Properties of Metals—R. L. Templin, Aluminum Company of America, New Kensington, Pa.
A Method of Determining the Orientation of the Crystal In Rolled Metal From X-Ray Patterns Taken By the Monochromatic Pinhole Method—W. P. Davey, C. C. Nitchie and M. L. Fuller, New Jersey Zinc Co., Palmerton, Pa.
Effect of Heat Treatment on Properties and Microstructure of Brittania Metal—B. Egeberg and H. B. Smith, International Silver Co., Meriden, Conn.

THURSDAY, SEPTEMBER 12

Morning Session

Meeting in Ball Room, Cleveland Hotel
H. W. Gillett, Chairman
W. E. Ruder, Vice-Chairman

10:00 A. M.—*Hot Aqueous Solutions For the Quenching of Steels*—H. J. French, International Nickel Co., Bayonne, N. J., T. E. Hamill, U. S. Bureau of Standards, Washington, D. C.
10:40 A. M.—*A Study of the Iron-Chromium-Carbon Constitutional Diagram*—Dr. V. N. Krivobok, Carnegie Institute of Technology, and M. A. Grossmann, Central Alloy Steel Co., Canton, Ohio.
11:20 A. M.—*Non-Destructive Testing*—E. A. Sperry, Sperry Development Company, Inc., Brooklyn, N. Y.
The Brittle Range in 18-8 Chromium-Nickel Iron (Presentation by title only)—H. H. Lester, Watertown Arsenal, Watertown, Mass.

Afternoon Session

Meeting Room, Public Auditorium
O. E. Harder, Chairman
J. S. Vanick, Vice-Chairman

2:00 P. M.—*Graphitization of PreQuenched White Cast Iron*—H. A. Schwartz, H. H. Johnson and C. H. Junge, National Malleable and Steel Castings Co., Cleveland.
2:25 P. M.—*Austenite and Its Decomposition*—Albert Sauveur, Harvard University, Cambridge, Mass.
3:00 P. M.—*High Strength Cast Iron*—E. J. Lowry, Detroit.
3:30 P. M.—*Crystal Structure of An Iron Phosphide*—James B. Friauf, Carnegie Institute of Technology, Pittsburgh.

FRIDAY, SEPTEMBER 13

Morning Session

SYMPOSIUM ON NITRIDING

Meeting in Ball Room, Cleveland Hotel

G. B. Waterhouse, Chairman
H. J. French, Adolph Fry, P. F. M. Aubert, Vice-Chairmen

10:00 A. M.—*The White Layer In Gun Tubes*—H. H. Lester, Watertown Arsenal, Watertown, Mass.

Observations Upon the Iron-Nitrogen System—Samuel Epstein, Illinois Steel Co., So. Chicago, Ill.

A Study of the Nitriding Process—V. O. Homerberg, and J. P. Walsted, Massachusetts Institute of Technology, Cambridge, Mass.

Researches on Nitriding Steels—Dr. O. E. Harder, University of Minnesota, Minneapolis, Minn., J. T. Gow and L. A. Willey, co-authors.

Afternoon Session

Meeting Room, Public Auditorium
G. B. Waterhouse, Chairman
H. J. French, Adolph Fry, P. F. M. Aubert, Vice-Chairmen

2:00 P. M.—*Investigations in Nitriding*—Robert Sergeson, Central Alloy Steel Corp., Canton, Ohio.

Short Time Nitriding of Steels In Molten Cyanides—A. B. Kinzel, and J. J. Egan, Union Carbide and Carbon Research Laboratories, Long Island City, N. Y.

A Few Practical Fundamentals of the Nitriding Process—H. W. McQuaid and W. J. Ketcham, Timken-Detroit Axle Co., Detroit.

The Use of Nitrided Steel in High Temperature-High Pressure Steam Service—V. T. Malcolm, Chapman Valve Manufacturing Co., Indian Orchard, Mass.

AMERICAN WELDING SOCIETY

MONDAY, SEPTEMBER 9

Morning Session

Hotel Statler

Registration facilities at Hotel Statler, commencing at 10:00 A. M. and at Public Auditorium, commencing at 12:00 noon.

Afternoon Session

Hotel Statler

2:00 P. M.—Meeting of Board of Directors, American Welding Society.

TUESDAY, SEPTEMBER 10

Morning Session

Hotel Statler

10:00 A. M.—*Business Meeting*—F. T. Llewellyn, president, presiding.

Technical Session
A. E. Gaynor, vice-president, presiding

10:30 A. M.—*The Effect on Design of the Use of Welding in the Manufacture of Electric Machinery*—H. G. Reist, General Electric Company, Schenectady, N. Y.

Cutting And Welding Steel Parts To Replace Castings—W. F. Buchanan, Bessemer Gas Engine Company.

Afternoon Session

Public Auditorium

H. L. Whittemore, Bureau of Standards, presiding.

2:00 P. M.—*Welding of Copper and Copper Alloys*—I. T. Hook, American Brass Co.

How To Test Welds—F. G. Tatnall, Southwark Foundry and Machine Co.

Evening Session

Cleveland Hotel

9:00 P. M.—National Metal Congress Dance.

WEDNESDAY, SEPTEMBER 11

Morning Session

8:30 A. M.—Starting from Hotel Statler, Inspection tour of three plants.

10:00 A. M.—Hotel Statler, Conference of research workers on fundamentals of welding, H. M. Hobart, Chairman, presiding.

Afternoon Session

Public Auditorium

J. J. Crowe, Air Reduction Sales Company, presiding.

2:00 P. M.—*Study of Nitride Needles*—P. Alexander, General Electric Company, Schnectady, N. Y.

Chemical Reactions of the Carbon Arc—G. E. Doan and E. Ekholm, Lehigh University.

A Metallographic Study of Some Metal Arc Welds—H. M. Boylston, Case School of Applied Science, Cleveland.

Metallographic Studies of Welding and Cutting—M. Yatsévitch, Watertown Arsenal, Watertown, Mass.

Evening Session

Hotel Statler

J. H. Edwards, chairman, presiding.

7:30 P. M.—Meeting of Structural Steel Welding Committee.

THURSDAY, SEPTEMBER 12

Morning Session

Hotel Statler

President F. T. Llewellyn, presiding.

9:30 A. M.—*Non-Destructive Testing of Welds With the Stethoscope and X-Ray*—C. O. Burgess, A. B. Kinzel and A. R. Lytle, Union Carbide and Carbon Research Laboratories, Inc., Long Island City, N. Y.

Welding Studies At The Watertown Arsenal—Major J. B. Rose, Ordnance Department, U. S. A., Watertown, Mass.

Stress Strain Characteristic of Welded Joints—J. H. Smith, University of Pittsburgh, Pittsburgh.

Afternoon Session

Public Auditorium

Joint Technical Session with A. S. M. E.

C. A. Adams, presiding.

2:00 P. M.—*Foreign Practice In Welding Of Boiler Tubes and Drums*—G. A. Orrok, New York City.

Automatic Arc Welding of Thin Sheets—W. L. Warner, General Electric Company, Schnectady, N. Y.

Non-Destructive Tests of Welds—Elmer A. Sperry, Sperry Development Company, Brooklyn, N. Y.

Evening Session

6:30 P. M.—Annual Banquet and Dance—Hotel Statler.

FRIDAY, SEPTEMBER 13

Morning Session

Hotel Statler

J. C. Lincoln, Lincoln Engineering Company, presiding.

10:00 A. M.—*Oxyacetylene Welding of Pipe Lines in the Field*—W. R. Ost, Air Reduction Sales Co., New York City.

Electric Welding of Field Joints of Oil and Gas Pipe Lines—H. C. Price, Welding Engineering Company.

Welding of Tubing and Pipes For Locomotives and Boilers—H. A. Woofter, Swift Electric Welder Company.

Afternoon Session

Hotel Statler

Prof. C. A. Adams, presiding.

2:00 P. M.—Meeting of American Bureau of Welding.

INSTITUTE OF METALS DIVISION OF A. I. M. E.

MONDAY, SEPTEMBER 9

Registration at Hotel Cleveland

TUESDAY, SEPTEMBER 10

Morning Session

Hotel Cleveland

Secondary Metal Symposium—T. A. Wright, Chairman; E. R. Darby, Vice-Chairman.

10:00 A. M.—*Manufacture of Wire Bars From Secondary Copper*—J. W. Scott and W. A. Scheuch, Western Electric Co., Hawthorne Station, Chicago.

Metal Recoveries In Secondary Aluminum Practice—R. J. Anderson, Fairmont Mfg. Co., Fairmont, W. Va.

Reclaiming Nonferrous Scrap Metals At Manufacturing Plant—F. N. Flynn, metallurgist, Milwaukee.

Utilization of Secondary Metals In the Red Brass Industry—H. M. St. John, Detroit Lubricator Co., Detroit.

Recovery of Waste From Tin-Base Babbitting Operations—P. J. Potter, Federal Mogul Corporation.

6:30 P. M.—Joint Dinner, Institute of Metals and Iron and Steel Division, A. I. M. E.

Speakers—Floyd T. Taylor, vice-president, Hanson, Van Winkle, Munning Company.

Dr. H. W. Gillett, Director, Battelle Memorial Institute.

9:30 P. M.—A. S. S. T. Dance, A. I. M. E. members invited.

WEDNESDAY, SEPTEMBER 11

Morning Session

Hotel Cleveland

10:30 A. M.—A. S. S. T. *E. D. Campbell Memorial Lecture*—Dr. Albert Sauveur.

Afternoon Session

Joint Meeting of Institute of Metals Division and American Society for Steel Treating.

P. D. Merica, Chairman

E. C. Bain, Vice-Chairman

2:00 P. M.—*Effects of Cold Working On the Physical Properties of Metals*—R. L. Templin, Aluminum Company of America, New Kensington, Pa.

Determining Orientation of Crystals In Rolled Metal From X-Ray Patterns Taken By the Monochromatic Pin-Hole

Method—W. P. Davey, C. C. Nitchie and M. L. Fuller, New Jersey Zinc Co., Palmerton, Pa.

Preparation of Microsections Of Tungsten Carbide—Dr. S. L. Hoyt, General Electric Co., Schenectady, N. Y.

Radiography As A Tool In the Metal Industry—W. L. Fink and R. S. Archer, Aluminum Company of America, Cleveland.

Effect of Heat Treatment On Properties and Microstructure of Brittania Metal—B. Egeberg and H. B. Smith, International Silver Co., Meriden, Conn.

THURSDAY, SEPTEMBER 12

Morning Session

Hotel Cleveland

S. L. Hoyt, Chairman

E. M. Wise, Vice-Chairman

10:00 A. M.—*Metallography of Commercial Thorium*—Edmund S. Davenport, Westinghouse Lamp Works, Bloomfield, N. J.

The Causes of Cuppy Wire—W. E. Remmers, Western Electric Co., Hawthorne Station, Chicago.

The Effect of Alloying On the Permissible Fiber Stress In Corrugated Zinc Roofing—E. A. Anderson, New Jersey Zinc Co., Palmerton, Pa.

The System Cadmium-Mercury—R. F. Mehl and C. S. Barrett, Naval Research Laboratory, Anacostia, D. C.

An Investigation To Determine The Eutectic Composition of Copper and Tin—G. O. Hiers and G. P. deForest, Research Laboratory, National Lead Co., Brooklyn, N. Y.

Notes On the Crystal Structure of the Alpha Copper-Tin Alloys—R. F. Mehl and C. S. Barrett, Naval Research Laboratory, Anacostia, D. C.

Deoxidation of Copper With Calcium and Properties of Some Copper-Calcium Alloys—E. E. Schumacher, W. C. Ellis and J. F. Eckel.

1:30 P. M.—Plant Inspection, Nela Park.

6:30 P. M.—A. S. S. T. Annual Banquet, Hotel Cleveland. A. I. M. E. members invited.

IRON AND STEEL DIVISION, AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS

TUESDAY, SEPTEMBER 10

Afternoon Session—2:00 P. M.

Public Auditorium

A. L. Feild, Chairman

The Change in Microstructure of Iron At the A_3 Transformation Point—B. A. Rogers, Western Electric Company, Chicago.

A New Development In Wrought Iron Manufacture—James Aston, Carnegie Institute of Technology, Pittsburgh.

Blast Furnace Filling and Size Segregation—C. C. Furnas and T. L. Joseph.

WEDNESDAY, SEPTEMBER 11

Morning Session—10:00 A. M.

Hotel Cleveland

C. B. Murray, Chairman

Fluorspar And Its Uses—Earl Brokenshire, Oglebay, Norton and Company, Cleveland.

Foreign Iron Ores—Charles Hart, Delaware River Steel Co., Chester, Pa.
Iron-Ore Sinter—G. M. Schwartz, University of Minnesota, Minneapolis, Minn.
The Bradley Process For the Beneficiation of Manganiferous Ores—Carl Zapffe, Northern Pacific Railroad, Brainerd, Minn.

THURSDAY, SEPTEMBER 12

Afternoon Session—2:00 P. M.

Public Auditorium

C. B. Waterhouse, Chairman

The Diffusion of Iron Oxide From Slag to Metal in the Open-Hearth Process—C. H. Herty, Jr., U. S. Bureau of Mines, Pittsburgh.
Experimental Data on the Equilibrium of the System Iron Oxide-Carbon in Molten Iron—A. B. Kinzel and J. J. Egan, Union Carbide and Carbon Research Laboratories, Long Island City, N. Y.
Rate of Carbon Drop and Degree of Oxidation of the Metal Bath in Basic Open Hearth Practice, II.—A. L. Feild, Union Carbide and Carbon Company, New York City.

IRON AND STEEL DIVISION, AMERICAN SOCIETY OF MECHANICAL ENGINEERS

WEDNESDAY, SEPTEMBER 11

Afternoon Session

Public Auditorium

Developments in Blast Furnaces, Design and Practice—Arthur G. McKee, Cleveland.
Ore-Handling Bridges—Alexander C. Brown, Industrial Brown Hoist Corp., Cleveland.
Oil Electric Locomotives in Steel Mill Transportation—W. L. Garrison, Ingersoll-Rand Co., New York City.

THURSDAY, SEPTEMBER 12

Afternoon Session

Public Auditorium

Joint Session with American Welding Society

Non-Destructive Tests of Welds—Elmer A. Sperry, Sperry Development Co., Brooklyn, N. Y., and President of American Society of Mechanical Engineers.
Foreign Practice in Welding Boiler Tubes and Drums—George A. Orrok, Consulting Engineer, New York City.
Automatic Arc Welding of Thin Sheets—W. L. Warner, General Electric Company, Schenectady, N. Y.

FRIDAY, SEPTEMBER 13

Morning Session

Hollenden Hotel

Alloy Steels in Iron and Steel Mill Equipment—M. J. R. Morris, Central Alloy Steel Corp., Massillon, Ohio.
Evolution of Drives For Mill Table Rollers—K. W. Feller, Schloemann Engineering Corp., Pittsburgh.

Afternoon Session

Public Auditorium

Joint Meeting with A. S. S. T.

Distribution of Heat in Combustion Furnaces—M. H. Mawhinney, Electric Furnace Co., Salem, Ohio.
Advantages of Producer Gas As a Fuel Compared with Other Forms of Fuel—

Victor Windett, Wellman, Seaver, Morgan Co., Cleveland.
Powdered Coal Cupola—D. H. Meloche, American Radiator Co., New York City.

OUTLINE OF PLANT INSPECTION

Tuesday Morning, September 10

National Tool Company
Lamson & Sessions Company
Otis Steel Company

Tuesday Afternoon, September 10

Case School of Applied Science

Wednesday Morning, September 11

Industrial Brownhoist Corporation
Columbia Axle Company
Lakeside Steel Improvement Company
White Motor Company
Warner and Swasey Company
Eaton Axle and Spring Company (Bumper Division)

Wednesday Morning—American Welding Society

Burdett Oxygen Company
Jos. T. Ryerson & Sons, Inc.
Lincoln Electric Company

Thursday Morning, September 12

Vichek Tool Company
Gears and Forgings, Inc.
Ferro Machine and Foundry Company
National Malleable and Steel Castings Company
American Steel and Wire Company (Cuyahoga Works and Central Furnace)
Cleveland and Pittsburgh Ore Docks

Thursday Afternoon—Institute of Metals

Nela Park

Friday Morning, September 13

National Acme Company
Hupp Motor Car Corporation
Great Lakes Aircraft Corporation
Cleveland Tractor Company
W. S. Bidle Co.

EXHIBITORS AT THE NATIONAL METAL EXPOSITION

The following is a complete list of exhibitors as of August 20 of those companies and individuals who will have exhibits at the National Metal Exposition.

A

Abrasive Company	Philadelphia
Acetylene Journal	Chicago
Air Reduction Sales Company	New York City
Ajax Electrothermic Corporation	Trenton, N. J.
Allegheny Steel Company	Brackenridge, Pa.
Allen Steel Company, Edgar	New York City
Allied Products Corporation	Detroit
Aluminum Company of America	Pittsburgh

American Brass Company	Waterbury, Conn.
American Car & Foundry Company	New York City
American Electric Furnace Company	Boston
American Engineering Company	Philadelphia
American Gas Association	New York City
American Gas Furnace Company	Elizabeth, N. J.
American Machinist	New York City
American Metal Market	New York City
American Steel & Wire Company	Chicago
Ampco Twist Drill Company	Jackson, Mich.
Andresen & Associates, F. C.	Pittsburgh
Armstrong-Blum Manufacturing Co.	Chicago
Armstrong Bros. Tool Company	Chicago
Armstrong Cork & Insulation Company	Pittsburgh
Automatic Nut-Thread Corporation	Philadelphia
Automatic Temperature Control Company	Philadelphia
Automotive Industries	New York City

B

Barnes Company, Inc., W. O.	Detroit
Bastian Blessing Company	Chicago
Bausch & Lomb Optical Company	Rochester, N. Y.
Bell & Gossett Company	Chicago
Bellevue Industrial Furnace Company	Detroit
Bellis Heat Treating Company	Branford, Conn.
Bethlehem Steel Company	Bethlehem, Pa.
Binghamton Flexible Shaft Company	Binghamton, N. Y.
Bliss & Laughlin, Inc.	Chicago
Botfield Refractories Company	Philadelphia
Bourne-Fuller Company	Cleveland
Bristol Company	Waterbury, Conn.
Brown Instrument Company	Philadelphia
Brown Lynch Scott Company	Monmouth, Ill.

C

Calorizing Company	Pittsburgh
Campbell, Inc., Andrew C.	Bridgeport, Conn.
Carboloy Company, Inc.	New York City
Carborundum Company (Abrasives)	Niagara Falls, N. Y.
Carborundum Company (Refractories)	Perth Amboy, N. J.
Carpenter Steel Company	Reading, Pa.
Case Hardening Service Company	Cleveland
Central Alloy Steel Corporation	Massillon, Ohio
Char Products Company	Indianapolis
Chemical Catalog Co., Inc.	New York City
Chicago Steel Foundry Company	Chicago
Chicago Steel & Wire Company	Chicago

Chrobaltic Tool Company	Detroit
Clark Tructractor Company	Battle Creek, Mich.
Cleveland Twist Drill Company	Cleveland
Climax Molybdenum Company	New York City
Clipper Belt Lacer Company	Grand Rapids, Mich.
Coats Machine Tool Company	New York City
Colonial Steel Company	Pittsburgh
Colt's Patent Fire Arms Mfg. Co.	Hartford, Conn.
Columbia Tool Steel Company	Chicago Heights, Ill.
Crucible Steel Company of America	New York City

D

Dardelet Threadlock Corporation	New York City
Darwin & Milner, Inc.	Cleveland
Dearborn Chemical Company	Chicago
DeSanno & Son, A. P.	Philadelphia
Detroit Alloy Steel Company	Detroit
DeWalt Products Company	Leola, Lancaster County, Pa.
Disston & Sons, Inc., Henry	Philadelphia
Donner Steel Company	Buffalo, N. Y.
Driver-Harris Company	Harrison, N. J.
Duraloy Company	Pittsburgh
Duriron Company	Dayton, Ohio

E

Eastman Kodak Company	Rochester, N. Y.
Eclipse Fuel Engineering Company	Rockford, Ill.
Egeberg, B.	Meriden, Conn.
Electric Steel Founders Research Group	Chicago
Electro Alloys Company	Elyria, Ohio
Electro Refractories Company	Buffalo, N. Y.
Elkon, Inc.	New York City
Evans-Wallower Zinc Company	New York City
Endicott Forging & Manufacturing Co.	Endicott, N. Y.
Enduro Nirosta Committee	New York City

F

Falls Electric Furnace Corporation	Buffalo, N. Y.
Federal Machine & Welder Company	Warren, Ohio
Ferner Company, R. Y.	Washington
Ferry Cap & Set Screw Company	Cleveland
Finkl & Sons Company, A.	Chicago
Firth-Sterling Steel Company	McKeesport, Pa.
Flannery Manufacturing Company	Pittsburgh
Ford Sales Company, J. B.	Wyandotte, Mich.
Fort Pitt Steel Casting Company	McKeepsort, Pa.

Fusion Welding Corporation	Chicago

G

Garlock Packing Company	Palmyra, N. Y.
Gas Products Corp.	Cleveland
Gathmann Engineering Company	Baltimore
Gehnrich Oven Company, Inc.	Long Island City, N. Y.
General Alloys Company	Boston
General Electric Company	Schenectady
Gibb Welding Machines Company	Bay City, Mich.
Globar Corporation	Niagara Falls

H

Halcomb Steel Company	Syracuse, N. Y.
Harrington Company	Philadelphia
Harris Calorific Company	Cleveland
Hayes, Inc., C. I.	Providence, R. I.
Haynes-Stellite Company	Kokomo, Ind.
Heppenstall Forge & Knife Company	Pittsburgh
Houghton & Company, E. F.	Philadelphia

I

Ideal Industrial Division	Cincinnati
Illinois Steel Company	Chicago
Illinois Testing Laboratories, Inc.	Chicago
Index Machinery Corporation	New York City
International Nickel Company	New York City
Interstate Iron & Steel Company	Chicago
Iron Age	New York City
Ivins' Steel Tube Works, Ellwood	Philadelphia
Irwin Lumber Company	Erie, Pa.

J

Jessop Steel Company	Washington, Pa.
Jessop & Sons, Inc., William	New York City
Johns-Manville Corporation	New York City
Jones & Laughlin Steel Corporation	Pittsburgh

K

Keller Mechanical Engineering Corp.	Brooklyn, N. Y.
Kelley-Koett Manufacturing Company	Covington, Ky.
Kelley Company, J. W.	Cleveland
Kemp Manufacturing Company, C. M.	Baltimore
Kenworthy, Inc., C. F.	Waterbury, Conn.
Keystone Lubricating Company	Philadelphia
K-G Welding & Cutting Company	New York City

L

Lakeside Steel Improvement Company	Cleveland
Lava Crucible Company of Pittsburgh	Pittsburgh
Lavino & Company, E. J.	Philadelphia
Lebanon Steel Foundry	Lebanon, Pa.
Leeds & Northrup Company	Philadalphia
Leitz, Inc., E.	New York City
Lincoln Electric Company	Cleveland
Linde Air Products Company	New York City
Ludlum Steel Company	Watervliet, N. Y.

M

Maehler Company, Paul	Chicago
Mahr Manufacturing Company	Minneapolis, Minn.
Manhattan Rubber Mfg. Company	Passaic, N. J.
Marburg Brothers, Inc.	New York City
McCann-Harrison Corporation	Cleveland
Metal & Thermit Corporation	New York City
Metals & Alloys	New York City
Michigan Steel Casting Company	Detroit
Midvale Company	Nicetown, Philadelphia
Milne & Company, A.	New York City
Milwaukee Die Casting Company	Milwaukee
Morse Twist Drill & Machine Company	New Bedford, Mass.

N

National Electric Light Association	New York City
New Jersey Zinc Sales Company	New York City
Northwestern Mfg. Company	Milwaukee
Norton Company	Worcester, Mass.
Nugent Steel Castings Company	Chicago

O

Ohio Steel Foundry Company	Springfield, Ohio
Olsen Testing Machine Company, Tinius	Philadelphia

P

Page Steel & Wire Company	Bridgeport, Conn.
Park Chemical Company	Detroit
Partlow Corporation	Utica, N. Y.
Pels & Company, Henry	New York City
Penton Publishing Company	Cleveland
Permutit Company	New York City
Pittsburgh Instrument & Machine Co.	Pittsburgh
Pressed Steel Company	Wilkes-Barre, Pa.
Production Machine Company	Greenfield, Mass.
Prosser & Son, Thomas	New York City

R

Ransohoff, Inc., N.	Cincinnati
Reeves Pulley Company	Columbus, Ind.
Reintjes Company, Geo. P.	Kansas City, Mo.
Republic Flow Meters Company	Chicago
Riehle Bros. Testing Machine Company	Philadelphia
Robertson Machine & Foundry Co., W.	Detroit
Rockwell Company, Stanley P.	Hartford
Roebling's Sons Company, J. A.	Trenton, N. J.
Roessler & Hasslacher Chemical Co.	New York City
Rotor Air Tool Company	Cleveland
Ruemelin Manufacturing Company	Milwaukee
Rustless Iron Corporation of America	New York City
Ryan, Scullen & Company	Philadelphia
Ryerson Company, Joseph T.	Cleveland

S

Safety Equipment Service Company	Cleveland
Scherr Company, Inc., George	New York City
Selas Company	Philadelphia
Sentry Company	Taunton, Mass.
Shakeproof Lockwasher Company	Chicago
Shawinigan Products Company	New York City
Shore Instrument & Manufacturing Co.	Jamaica, N. Y.
Simonds Saw & Steel Company	Fitchburg, Mass.
Sivyer Steel Casting Company	Milwaukee
Smith & Sons, Inc., David H.	Brooklyn, N. Y.
Snap-On Wrench Company	Chicago
Southern Manganese Steel Company	Chicago
Southwark Foundry & Machine Company	Philadelphia
Spencer Turbine Company	Hartford, Conn.
Square D Company	Detroit
Stamets, Wm. K.	Cleveland
Standard Alloy Company	Cleveland
Standard Equipment Company, Inc.	New Haven, Conn.
Steel City Testing Laboratory	Detroit
Steel Publications	Pittsburgh
Stoody Company	Whittier, Cal.
Strong Carlisle & Hammond Company	Cleveland
Stuart & Company, D. A.	Chicago
Sullivan Machinery Company	Chicago
Surface Combustion Company	Toledo, Ohio

T

Taylor Winfield Corporation	Warren, Ohio
Thompson Grinder Company	Springfield, Ohio
Timken Steel & Tube Company	Canton, Ohio

Toledo Scale Company	Toledo, Ohio
Tomkins-Johnson Company	Jackson, Mich.
Torchweld Equipment Company	Chicago
Trent Company, Harold E.	Philadelphia

U

Una Welding & Bonding Company	Cleveland
United Engineering Society	New York City

V

Vanadium Alloys Steel Company	Latrobe, Pa.
Vanadium Corporation of America	New York City
Van Dorn Electric Tool Company	Cleveland
Victor X-Ray Corporation	Chicago
Victor-Peninsular Division	Detroit

W

Welding Engineer	Chicago
Weldit Acetylene Company	Detroit
Westinghouse Elec. & Mfg. Company	East Pittsburgh
Wheeling Mold & Foundry Company	Wheeling, W. Va.
Wheelock, Lovejoy & Company, Inc.	Cambridge, Mass.
Whitman and Barnes, Inc.	Detroit
Wickwire Spencer Steel Company	New York City
Wiedemann Company	Philadelphia
Willson Products, Inc.	Reading, Pa.
Wilson-Maeulen Company	New York City

Z

Ziv Steel & Wire Company	Chicago

News of the Chapters

STANDING OF THE CHAPTERS

DURING the month of July there were 85 new and reinstated members, while 55 were lost through non-payment of dues and 6 through resignations and deaths, leaving a net gain of 24 members for the month.

The total membership of the society on July 1, 1929, was 5,573 and the chapters appear in the following order of membership.

GROUP I		GROUP II		GROUP III	
1. Chicago	550	1. Los Angeles	226	1. Ontario	139
2. Detroit	490	2. Milwaukee	149	2. Tri City	107
3. Pittsburgh	397	3. New Jersey	148	3. New Haven	97
4. Philadelphia	340	4. Hartford	142	4. Worcester	77
5. New York	330	5. Lehigh Valley	141	5. Rochester	76
6. Cleveland	325	6. Golden Gate	137	6. Washington	69
7. Boston	256	7. Cincinnati	105	7. Rhode Island	67
		8. St. Louis	99	8. Schenectady	63
		9. Dayton	90	9. Southern Tier	49
		10. Indianapolis	87	9. Rockford	49
		10. Buffalo	87	11. Columbus	46
		12. Syracuse	85	12. Springfield	38
		13. Canton-Mass.	84	13. Notre Dame	30
		14. Montreal	77	14. Fort Wayne	26
		15. North West	70		

GROUP I—Chicago in first place increased its lead over Detroit in second place to sixty members, while the other chapters in this group remained in the same positions, although Cleveland showed a net increase of five members.

GROUP II—Los Angeles with a gain of five and a total of 226 still heads this group; while New Jersey with a gain of six is just one behind Milwaukee in second position. Lehigh Valley is one behind Hartford in position four, having passed Golden Gate and advanced from sixth to fifth place.

Indianapolis with a loss of four permits Dayton to go into position nine; while Buffalo with a gain of three advances from thirteenth to a tie with Indianapolis for position ten, passing in the meantime Syracuse and Canton-Massillon.

GROUP III—For the first time for a number of months the Ontario Chapter shows a loss instead of a gain, having had its membership reduced from 141 to 139. Tri City with a gain of three is thirty-two behind Ontario.

The other chapters remain the same and the tie existing in June between Southern Tier and Rockford remains for the month of July.

Items of Interest

DR. ANSON HAYES has been appointed director of research and W. J. Beck has been appointed as assistant to the general manager of the American Rolling Mill Co., Middletown, O. Both men are members of the A. S. S. T. Dr. Hayes has been chief of the chemical division of the company for the past year and a half, previous to that he held the chair of Physical Chemistry at Iowa State College. Mr. Beck for 19 years has been director of research for the company. He will now have direct charge of the development of electrical sheets.

The Bethlehem Steel Co., Bethlehem, Pa., has issued a bound booklet No. 26-A, entitled "Bethlehem Mayari Pig Iron." This gives applications and analysis specifications for the use of Mayari iron for special purposes. About half of the booklet is devoted to a discussion of cupola practice and the metallurgy of iron with nickel-chromium.

The above company has also issued a booklet entitled "Silvery Mayari Pig Iron." This describes a product said to be a new general-purpose pig iron for making super-strength castings.

"Practical Steelmaking" is the title of a recent book by Walter Lister being distributed by Instruments Publishing Co., 1117 Wolfendale St., Pittsburgh. This book is intended to give in simple language and concise form the results of the author's 20 years' experience of practical steelmaking. It is believed that the literature has heretofore lacked information of practical value for the man working or going to work at the furnace.

Henry S. Rawdon has recently been appointed chief of the Division of Metallurgy, Bureau of Standards, Washington, succeeding Dr. H. W. Gillett, resigned. Mr. Rawdon was in charge of optical metallurgy of the bureau.

The recently-organized Michiana Products Corp. announces that it has taken over the properties of the Chrobaltic Tool Co., and the Sheet Steel Products Co., both of Michigan City, Ind. It is stated that the Chrobaltic division will continue to manufacture heat and acid resisting alloy castings, and with the additional foundry recently completed is in a position to serve its customers in an even more effective way than in the past. The Sheet Steel Products division will continue the manufacture and service of Hall-Winslow line of oil filters. O. M. Carry is president of the new Michiana Products Corp., with offices at Chicago, and W. B. Sullivan first vice-president and general manager, located at the plants at Michigan City, Ind.

Bulletin No. 6 describing a variety of blowpipes, tips and burners is being distributed by the American Gas Furnace Co., Elizabeth, N. J.